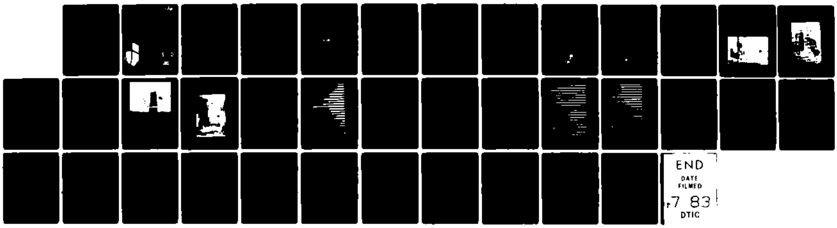
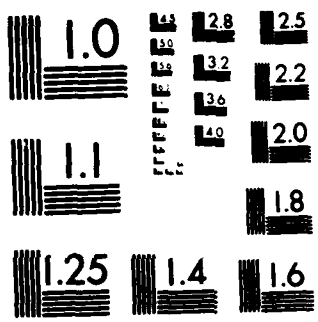
AD-A128 989 SOUND POWER MEASUREMENTS ON THE M1E1 ENGINE AND TOTAL POWER PACK(U) CONSTRUCTION ENGINEERING RESEARCH LAB (ARMY) CHAMPAIGN IL P D SCHOMER MAY 83 CERL-TR-N-150 1/1

UNCLASSIFIED IAO-82065 F/G 19/3 NL





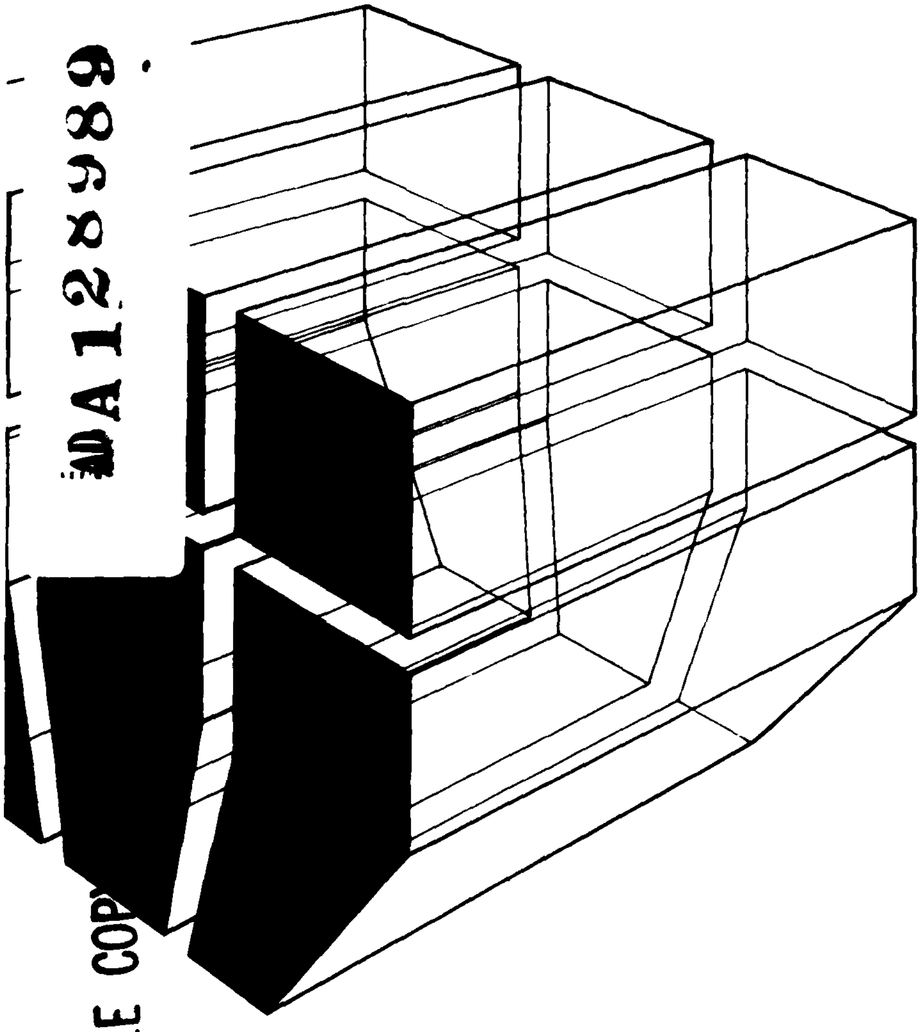
MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

construction engineering research laboratory

United States Army Corps of Engineers
...Serving the Army
...Serving the Nation

Technical Report N-150
May 1983

SOUND POWER MEASUREMENTS ON THE M1E1 ENGINE AND TOTAL POWER PACK



by
Paul D. Schomer

Approved for public release; distribution unlimited.

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER CERL-TR-N-150	2. GOVT ACCESSION NO. A128 989	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) SOUND POWER MEASUREMENTS ON THE M1E1 ENGINE AND TOTAL POWER PACK		5. TYPE OF REPORT & PERIOD COVERED FINAL
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Paul D. Schomer		8. CONTRACT OR GRANT NUMBER(s) IA082065
9. PERFORMING ORGANIZATION NAME AND ADDRESS U.S. ARMY CONSTRUCTION ENGINEERING RESEARCH LABORATORY P.O. BOX 4005, CHAMPAIGN, IL 61820		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Headquarters, U.S. Army Materiel Development and Readiness Command (HQ DARCOM) Alexandria, VA 22333		12. REPORT DATE May 1983
		13. NUMBER OF PAGES 33
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Tanks (combat vehicles)
M1E1 tank
engine noise

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A new technique to measure sound power was used to gather one-third octave emissions data on the M1E1 engine (AGT 1500) at the Stratford Army Engine Plant, CT and on the M1E1 power pack at Aberdeen Proving Ground, MD. To calculate sound power, acoustic intensity (the product of the scaler pressure and the vector velocity) was measured and integrated over an arbitrary surface enclosing the source. The data gathered and test results show this new technique is very powerful and robust and is applicable to many machinery quieting, source emission, or sound transmission measurements.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

BLANK PAGE

FOREWORD

This research was conducted for the Headquarters, U.S. Army Materiel Development and Readiness Command (HQ DARCOM) under Reimbursable Order No. IAO82065 (15 June 1982), "Perimeter Noise Warning System." The HQ DARCOM Technical Monitor was Mr. Duane Benton, DRCIS-A.

This research was performed by the Environmental (EN) Division of the U.S. Army Construction Engineering Research Laboratory (CERL). Dr. R. K. Jain is Chief of CERL-EN.

COL Louis J. Circeo is Commander and Director of CERL, and Dr. L. R. Shaffer is Technical Director.

CONTENTS

TABLES

FIGURES

SOUND POWER MEASUREMENT ON THE M1E1 ENGINE AND TOTAL POWER PACK

1 INTRODUCTION

Background

The M1E1 tank's power plant, a turbo-shaft engine, is very different from the traditional diesel or gasoline reciprocating engine, and represents a departure in Army technology for overground vehicles. One of the factors inherent in the turboshaft engine as compared to the diesel engine is increased noise levels. As such, engine construction, rework, and training facilities require degrees of acoustical treatment not required for the more traditional diesel engine.

Purpose

The purpose of this study was to (1) determine acoustic sound-power emission levels versus frequency for the M1E1 engine as it operates within a training-type facility (a) loaded on a water break (dynamometer-type device) and (b) unloaded, but with transmission engaged; and (2) develop options and directions for the appropriate acoustical design of engine test and training facilities.

2 APPROACH

The sound power in watts (P) is simply the integral of the acoustic intensity (I) over some surface (S) enclosing the source:

$$P = \int_S I \, ds \qquad \text{[Eq 1]}$$

This integral can be approximated arbitrarily closely by the summation of the average acoustic intensity over a set of finite areas multiplied by each area:

$$P \simeq \sum_i I_i \, \Delta S_i \qquad \text{[Eq 2]}$$

where I_i is the intensity on the i^{th} discrete area, and ΔS_i is its surface area. (In the limit as $\Delta S \rightarrow 0$ and $i \rightarrow \infty$, Eq 2 becomes Eq 1.) In practice, these discrete areas should be flat rectangular surfaces with areas ranging up to 2 m^2.

Figure 1 shows a hypothetical, six-sided, box-like surface enclosing a noise source. The "floor" is a hard reflecting surface which absorbs no power. The summation of the average acoustic intensity over the other five surfaces multiplied by the surface area of each surface yields the power output of this device in watts. The sixth surface, the floor, is considered an ideal reflector. Power emitted downwards by the device is reflected by the floor and so exists through one of the other five surfaces.

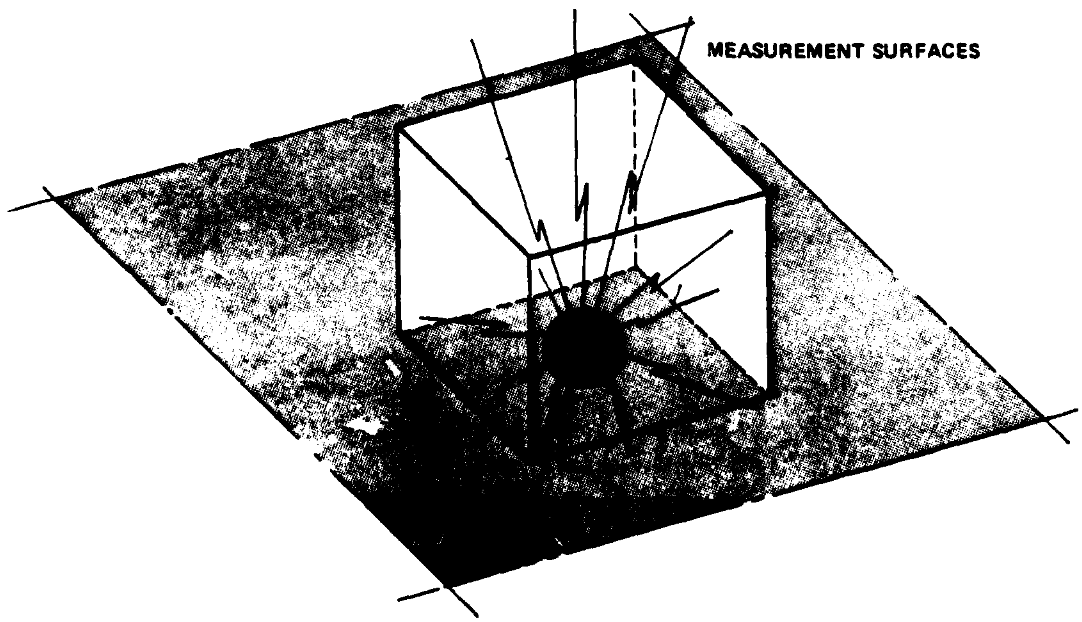


Figure 1. A sound source enclosed by a hypothetical rectangular surface and resting on a hard reflecting surface.

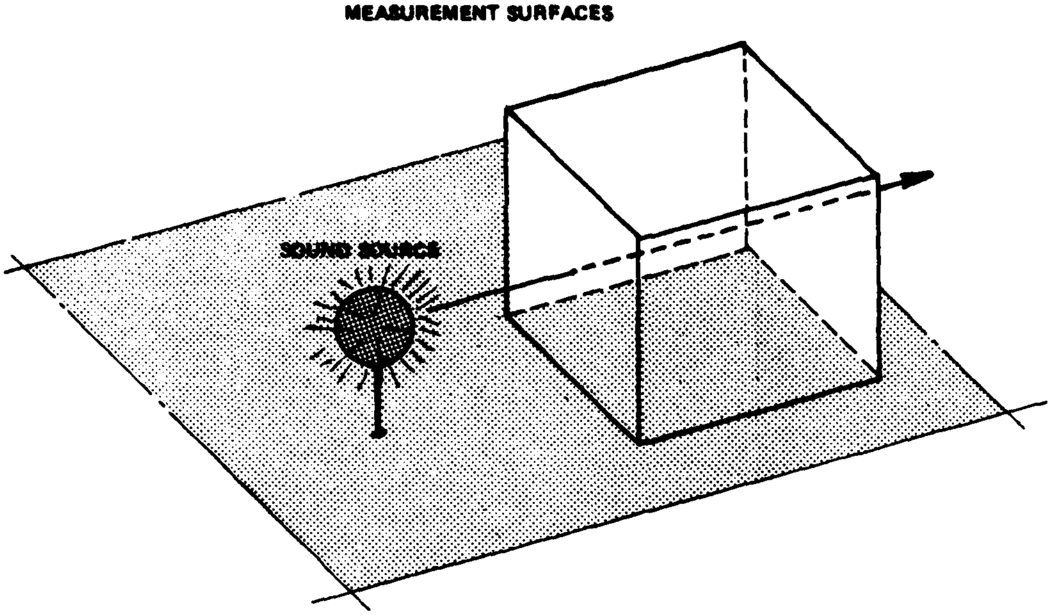


Figure 2. The sound "rays" from any external source enter the near measurement surface (negative power flow out of the surface) and exit through another face of the overall measurement surface (positive power flow out). The net result over the entire measurement surface is zero.

Figure 2 shows the effect of an external noise source in the vicinity of the measurement. As long as there is no significant absorption within the cube, sound entering one surface must exist within that surface or another surface so the net acoustic power from the external source flowing outward through the surface is zero. Similarly since the net flow is zero, reflections off a wall or other nearby objects (Figure 3) also fail to

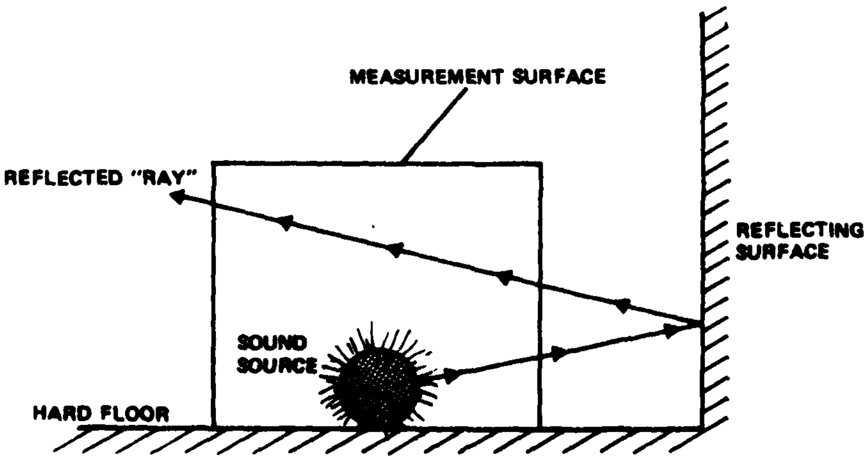


Figure 3. Sound "ray" from the source which reflects off the nearby surface may enter (negative power flow out) and exit (positive power flow out) the measurement surface. The net contribution of the reflected "ray" over the entire measurement surface is zero.

add to the acoustic power measurement. (The reflection off the wall can also be thought of as a mirror image source; hence, its contribution is zero.)

Thus, the measurement of acoustic intensity over a surface enclosing only the acoustic source of interest offers a relatively simple and economic means to develop the acoustic sound power output of a device while (1) in actual use and (2) in the presence of other noise sources and reflecting surfaces. The major requirement for these measurements is a sound intensity meter.

Recently, the U.S. Army Construction Engineering Research Laboratory (CERL) purchased a newly developed Bruel and Kjaer sound intensity meter. Intensity is defined as the product of the scaler acoustic pressure and the vector acoustic velocity. In this intensity meter, the acoustic pressure is approximated by the average of two microphones spaced front-to-front at typically 12 mm (Figure 4). The sound velocity ($\overline{v}$) is related to the pressure (p) by Eq 3, where the partial derivative of velocity with respect to time is proportional to the pressure gradient

$$\rho_0 \frac{\delta \overline{v}}{\delta t} = -\overline{\text{grad}}\, p \qquad \text{[Eq 3]}$$

where ρ_0 is the density of air. The acoustic velocity is approximated as the integral of the pressure difference (between the two microphones) with respect to time (t).

So, in this meter, the intensity is approximated as:

$$I = k \left(\frac{p_1(t) + p_2(t)}{2}\right) \left(\frac{1}{T}\int_0^T \frac{p_1(t) - p_2(t)}{2\Delta} dt\right) \qquad \text{[Eq 4]}$$

where p_1 and p_2 are the pressures measured by the two microphones separated by the small distance (typically 12 mm), and k is a proportional constant.

This sound intensity meter was used to measure the sound power output in one-third octave frequencies for the M1E1 engine and transmission operated in its training mode at Aberdeen Proving Ground, MD and for the M1E1 engine operating with a water break (dynamometer-type of device) at the Stratford Army Engine plant, CT (where they are built). Two engines were measured at the Stratford plant, one outdoors and one indoors. In all three cases, complex rectangular surfaces were mapped out over the engine, the average intensity within each rectangle of the surface was measured, and the acoustic power developed.

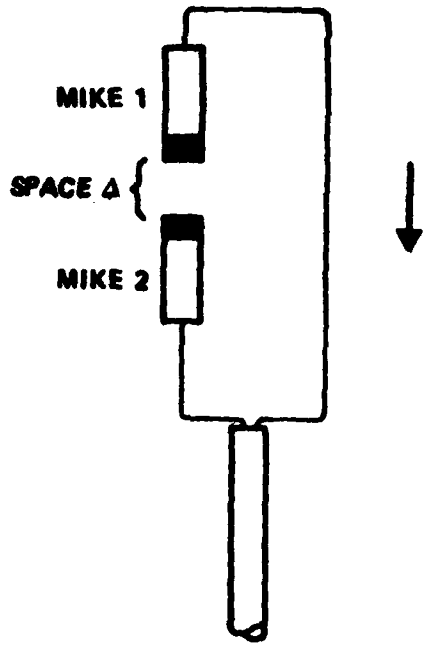


Figure 4. Two-microphone sensor. The space between the two microphones is Δ, typically 12 mm. The pressure is the average

$$\frac{p_1(t) + p_2(t)}{2}.$$

The velocity (v) in the direction of the arrow is

$$-\frac{1}{\rho_0}\int \frac{p_1(t) - p_2(t)}{2\Delta}.$$

where ρ_0 is the density of air.

3 MEASUREMENTS AND RESULTS

The current M1E1 engine repair training facility at Aberdeen Proving Ground is a large, open, garage-type structure. The power pack (i.e., the engine complete with transmission and other auxiliary equipment) is removed as a unit from the tank chassis, and students

are taught various ways to tuneup the power pack in the field. In its noisiest mode, the engine operates at rated speed with the transmission engaged, but with no load on the transmission. At Aberdeen (and at any new facility), an exhaust hood is fit over the engine exhaust to duct the hot exiting gases up a stack and out through the roof. At Aberdeen, the roof line is about 25 ft (7.6 m) above the floor. The exhaust duct is made from heavy gauge steel.

At both Aberdeen and Stratford, CERL built a rectangular surface over the engine and transmission pack (Figure 5) using thin-wall conduit and string. This construction was done in two phases. First, the engine and transmission were enclosed, mapped, and measured. Second, the exhaust stack was enclosed and measured (Figure 6). Figure 7 shows the set of surface areas CERL used to develop the acoustical intensity for the main engine, chassis, and stack at Aberdeen. This figure also shows the labeling scheme and dimensions.

The average intensity over any rectangle was developed by sweeping the sensor over the surface, while holding the sensor normal to the surface (Figure 8). This averaging was done at least three times by three different persons for 32 seconds during each averaging operation. Thus, a very good average was automatically developed by what amounts to at least a 96-second integral. Three different persons were used to average out potential individual bias.

Two measurement problems were encountered at Aberdeen. First, the transmission and the auxiliary equipment includes two large cooling fans, the larger having a capacity of 6000 cfm (2.8m^3/s). Because it is impossible to make measurements in the presence of this high-velocity flow (the noise generated by the air turbulence at the microphone leads to erroneous results), a baffling device was constructed entirely within the measurement enclosure to deflect and channel the air while it gradually slowed in velocity (Figure 9). Since this baffle device was entirely within the enclosure, the net power measured over the closed surface still must represent the sound power output of the device (a further indication of how vigorous and robust acoustic intensity is as a measurement method).

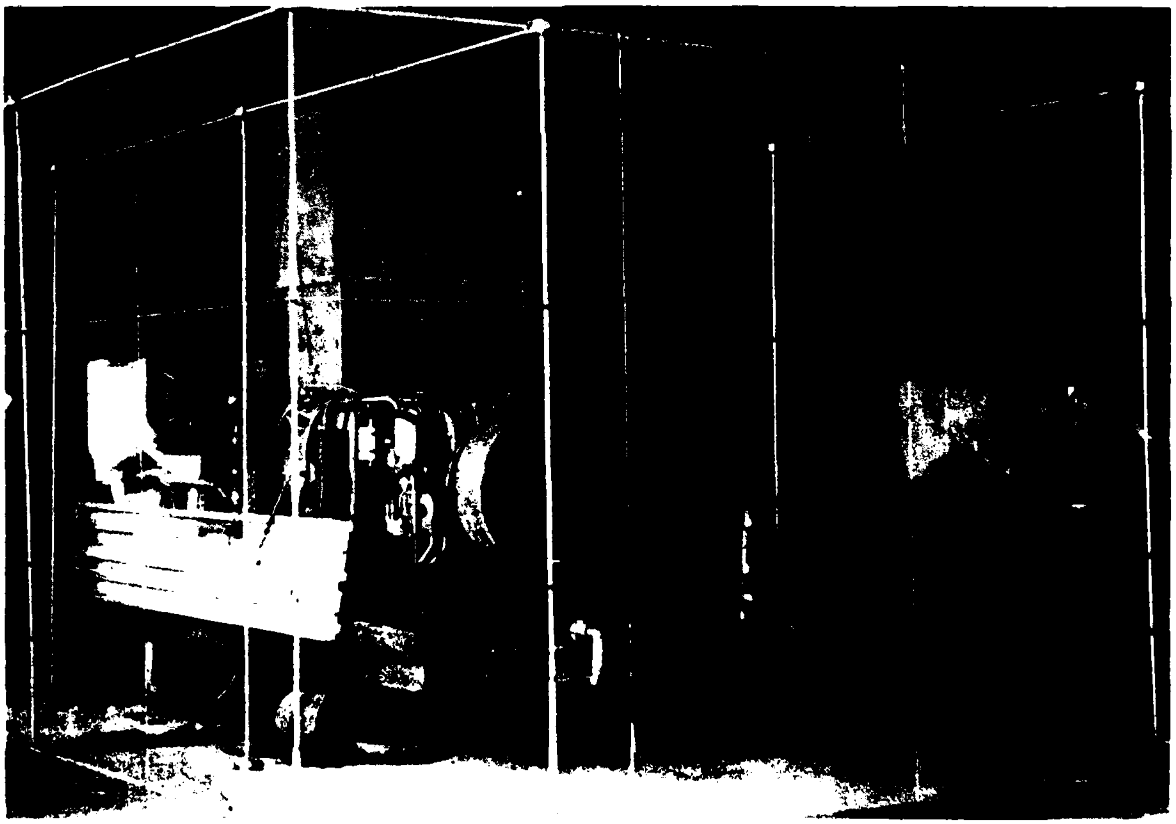


Figure 5. Main grid at the Aberdeen measurements.

A second problem was the height, location and temperature of the exhaust exit. The exit was located high in the air. The exhaust temperatures were greater than those temperatures the microphone intensity sensor could withstand (the exhaust temperature near the engine is 900°F [477°C]). In terms of the interior design for a new training facility, the lack of data for the exhaust does not represent a problem, since it is the acoustic power internal to the structure which dictates the structure's design. The exhaust represents a separate problem, since it will not contribute significantly to the internal acoustic levels. In the case of Aberdeen, external noise in no way represents an environmental problem. Thus, the entire design is

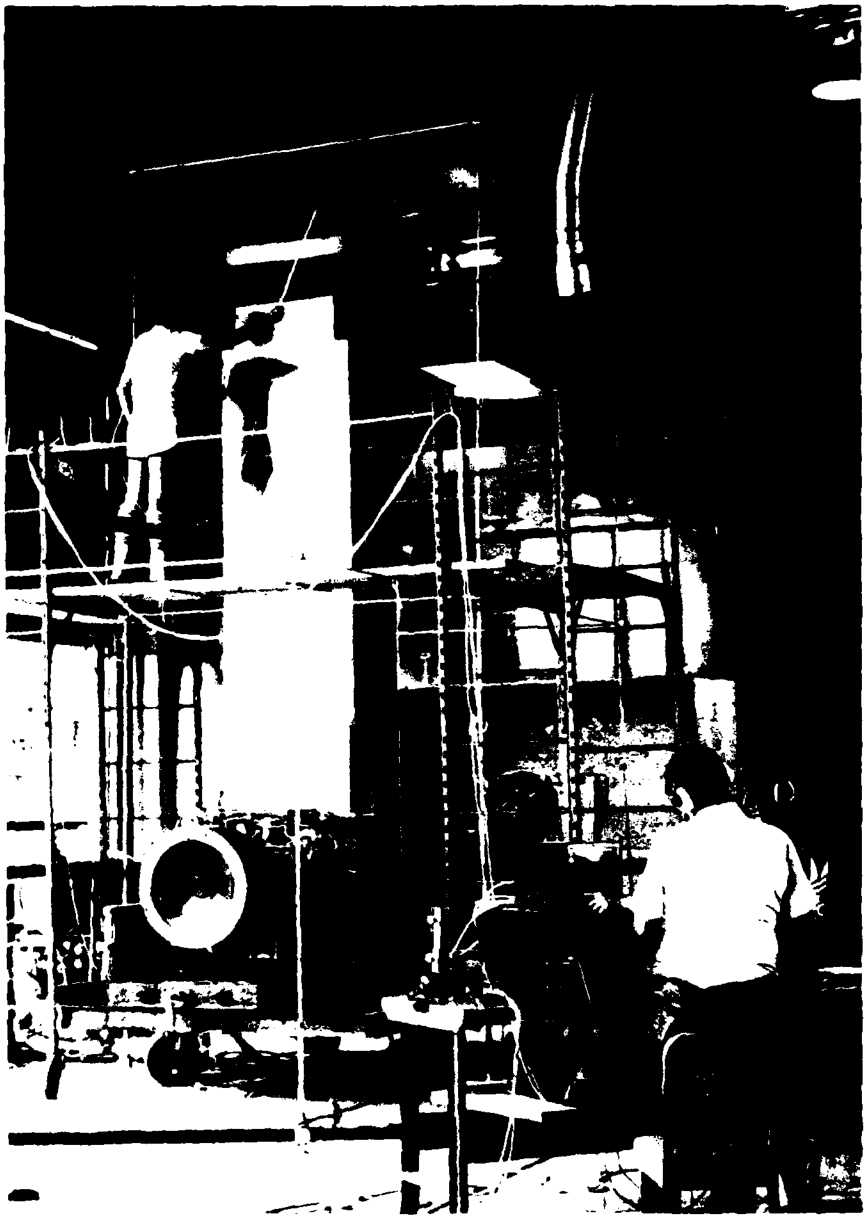


Figure 6. Stack grid at the Aberdeen measurements (note the analyzer and display in the foreground and the plywood baffle in the backg ound).

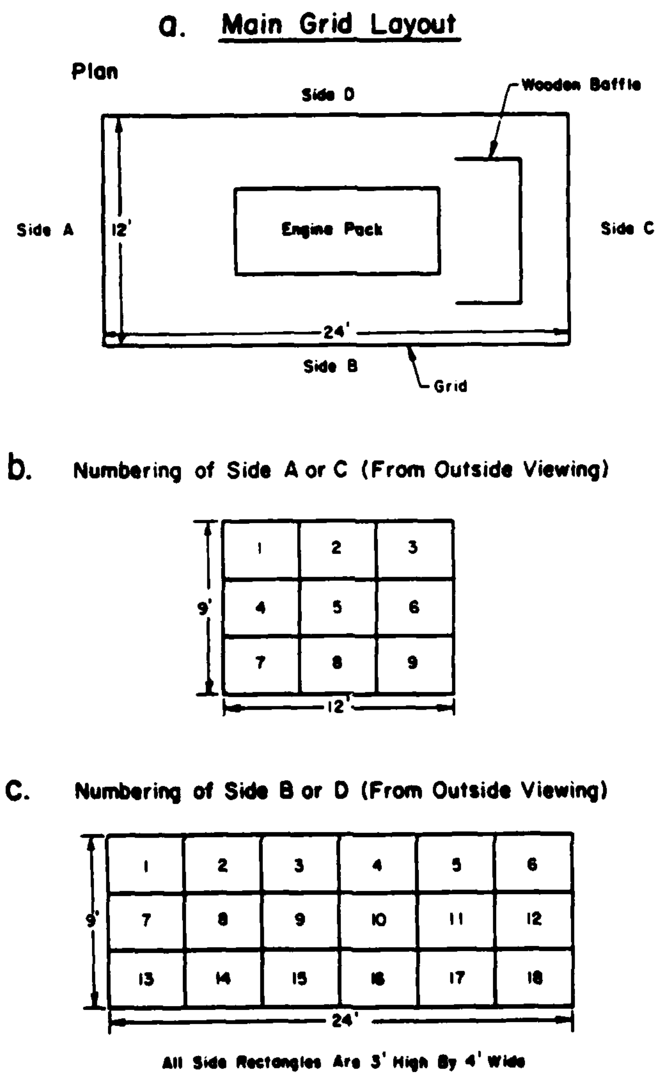
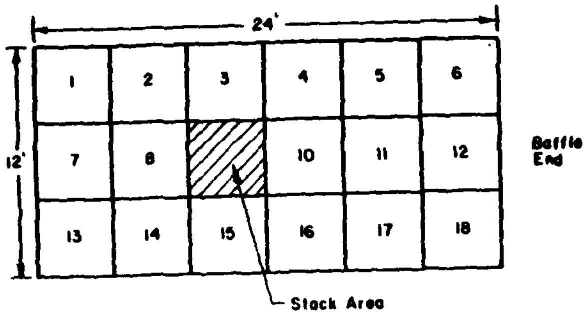


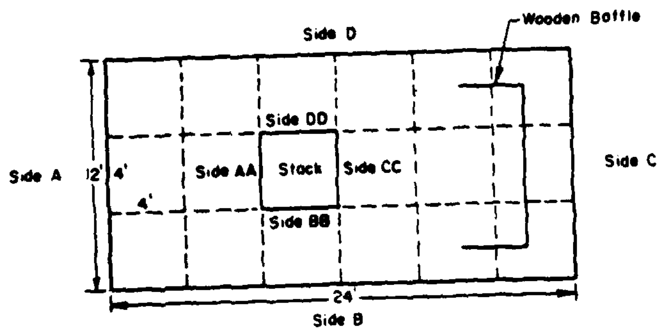
Figure 7. Aberdeen test configuration.

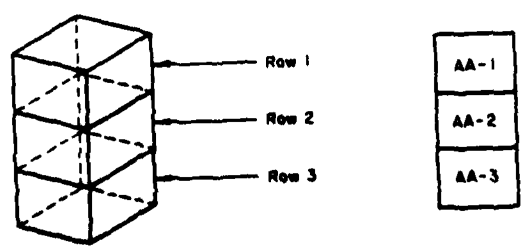
d. **Top of Main Grid**
(View Down From Above)



All Top Rectangles Are 4' Squares

e. **Stack Grid Layout**
(Located Above Section 9 of Main Grid Top)





f. All Stack Rectangles Are 3' High By 4' Wide

Figure 7. (Cont'd.)

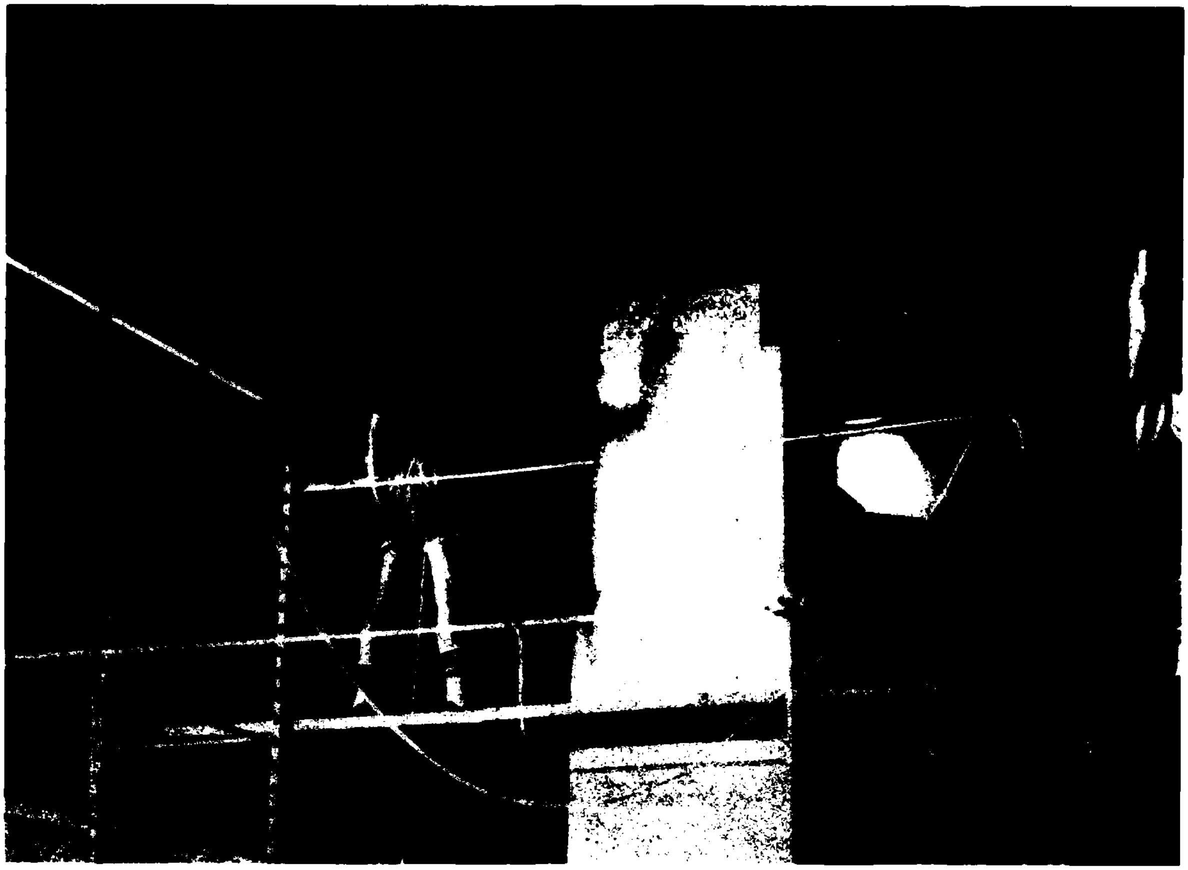


Figure 8. "Sweeping" a section of the stack grid at the Aberdeen measurements.

dictated by the sound power data developed by this study.

Table 1 lists the sound power level (PWL) in decibels developed by one-third octave bands (re: 10^{-12} watts)* for the engine and transmission at Aberdeen. Figure 10 plots these results. Table 1 also lists the data by side (Figure 7). Appendix A explains the calculation of the data in Table 1 and contains the entire data set.†

Two M1E1 engines were measured at the Stratford Army Engine Plant, one outdoors in the development test area and one indoors in an existing production test cell. Similar, although not identical, areas were mapped for the outside and inside measurements. The outdoor measurements ducted through a short section of pipe into the open air. The indoor measurements ducted through a vertical stack which rose about 20 ft (6 m) above the roof level. The outside engine was well worn and could only develop 900 hp (666 kW). The inside engine was new and was tested at 1350 hp (999 kW). The exhaust temperature directly off the engine is 1400°F (752°C), and at high velocity. Hence, it was impossible to directly measure the exhaust.

Similar, but not identical rectangular enclosures were built for the outside and inside measurements (Figures 11 and 12, respectively). Table 2 lists the sound power levels emitted by each of the engines in the various one-third octave bands. (Appendix B contains the entire data set.) Figure 13 shows these same data. The main contribution to the sound power for both the outdoor and indoor engine test came through Square 1, the square facing the engine air inlet. The data for Square 1 are tabulated in Table 3 and illustrated in Figure 14. In each case, all of the other squares contributed substantially less acoustic power (at least 10 dB less). No other areas predominated.

*The power (P) in watts equals $10^{(PWL/10)} \times 10^{-12}$.

†The data for two squares per side at Aberdeen included frequencies down to 25 Hz. These generally "tailed off" and were so low in level relative to the higher frequencies that only data from 100 Hz up were generally gathered and reported.

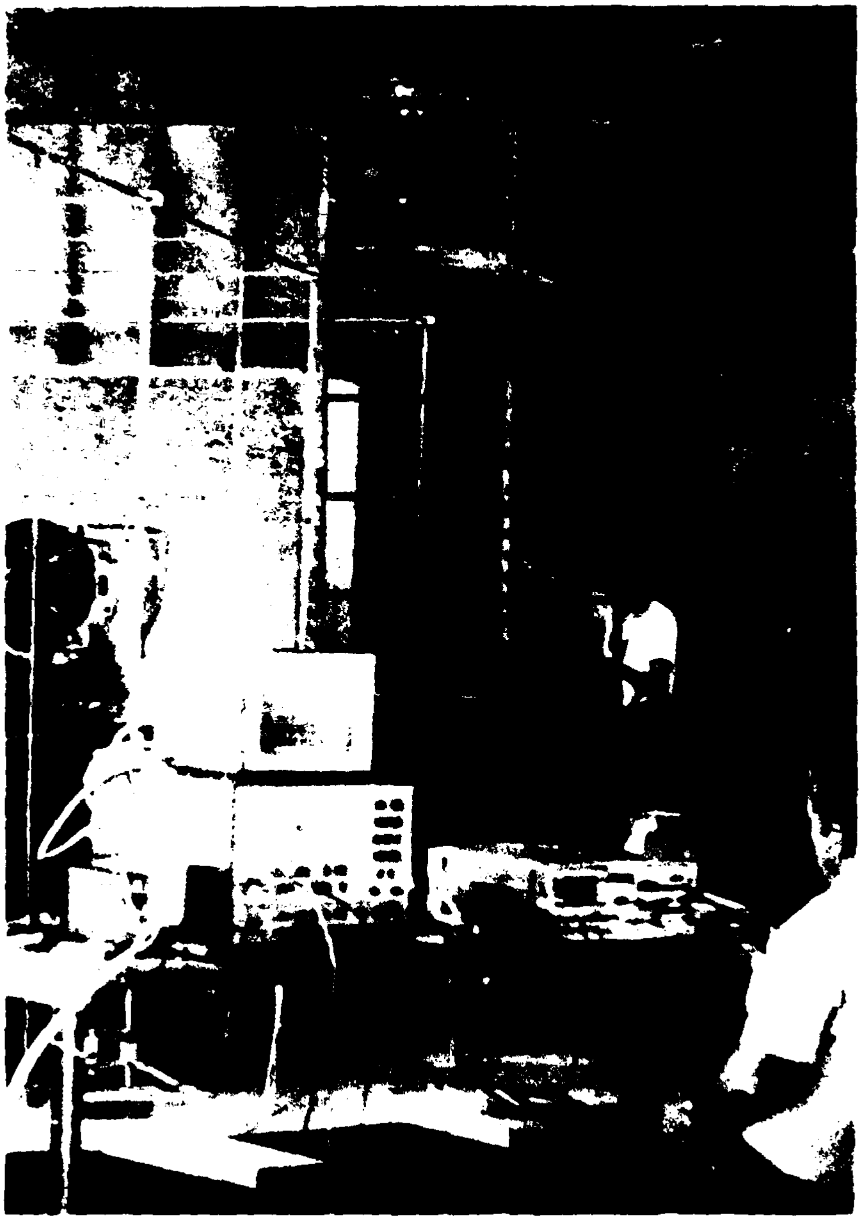


Figure 9. Plywood baffle (background) used at Aberdeen to deflect air stream from power pack fans.

Table 1
Aberdeen Sound Power Levels by Side and Total (Re: 10^{-12} watts)

Location: Test: Date: 15 Sep 82

Band/Freq	Box Mike/Spacer N	A	B	C	D	E	AA to DD	Total
20	100	89.1	85.8	87.2	92.8	80.2	83.4	96.0
21	125	87.5	84.5	78.7	93.1	83.7	78.7	95.1
22	160	87.1	−90.5	−84.2	89.2	−91.6	−88.8	−93.5
23	200	90.1	91.9	80.8	95.1	92.6	90.2	99.4
24	250	91.2	91.0	79.7	95.4	91.2	85.7	99.0
25	330	91.6	87.5	−81.2	95.4	84.4	−81.6	97.4
26	400	96.2	96.5	85.7	99.5	96.9	93.4	104.0
27	500	94.1	94.2	86.4	98.8	95.3	90.1	102.5
28	630	98.5	98.4	89.3	102.1	98.6	92.0	106.0
29	800	97.6	99.1	92.6	102.4	99.4	93.4	106.4
30	1 K	99.6	100.7	89.3	104.4	101.4	93.9	108.1
31	1.25 K	111.6	114.9	98.5	115.6	115.1	106.5	120.8
32	1.6 K	104.2	104.8	92.0	109.3	105.2	98.2	112.7
33	2 K	100.5	100.0	87.0	105.0	100.2	94.1	108.2
34	2.5 K	104.6	103.8	84.2	108.1	105.0	97.7	111.9
35	3.2 K	100.3	98.5	82.5	104.6	98.6	94.1	107.5
36	4 K	100.3	98.4	−76.1	105.5	97.2	94.8	107.8
37	5 K	98.3	93.7	−76.9	103.1	93.8	91.4	104.9
38	6.3 K	96.3	90.3	69.2	100.7	92.7	89.1	102.9
39	8 K	94.7	86.2	−63.0	98.4	89.7	87.3	100.7
40	10 K	94.9	85.2	72.2	97.5	89.6	85.9	100.2
	Total	114.5	116.3	101.5	118.7	116.6	109.0	123.0

Table 2
Stratford Inside and Outside Tests– Total PWL (Re: 10^{-12} watts)

Location: Test: Date:

Band/Freq	Box Mike/Spacer N	Inside	Outside
20	100	104.8	103.7
21	125	95.8	99.2
22	160	−89.0	91.8
23	200	94.4	98.1
24	250	90.7	99.8
25	320	95.7	102.4
26	400	104.1	107.3
27	500	94.8	105.6
28	630	98.5	108.7
29	800	100.8	106.7
30	1 K	100.9	105.9
31	1.25 K	106.5	107.4
32	1.6 K	112.7	110.9
33	2 K	116.5	115.4
34	2.5 K	110.4	112.9
35	3.2 K	113.1	119.9
36	4 K	114.9	115.9
37	5 K	109.1	114.2
38	6.3 K	110.9	119.7
39	8 K	112.9	114.5
40	10 K	113.1	115.7
	Total	123.0	126.3

Table 3
Stratford "Box 1" Inside and Outside Test (PWL Re: 10^{-12} watts)

Location: Test: Date:

Band/Freq	Box Mike/Spacer N	Inside	Outside
20	100	−100.9	0
21	125	0	0
22	160	0	0
23	200	0	0
24	250	0	96.0
25	320	0	0
26	400	0	100.0
27	500	0	103.5
28	630	0	104.5
29	800	92.0	102.3
30	1 K	96.7	103.3
31	1.25 K	104.5	105.4
32	1.6 K	111.8	110.2
33	2 K	116.2	116.3
34	2.5 K	109.4	113.0
35	3.2 K	112.6	121.0
36	4 K	114.4	116.0
37	5 K	108.4	113.5
38	6.3 K	110.4	120.5
39	8 K	112.8	113.7
40	10 K	113.0	115.6
	Total	122.3	124.7

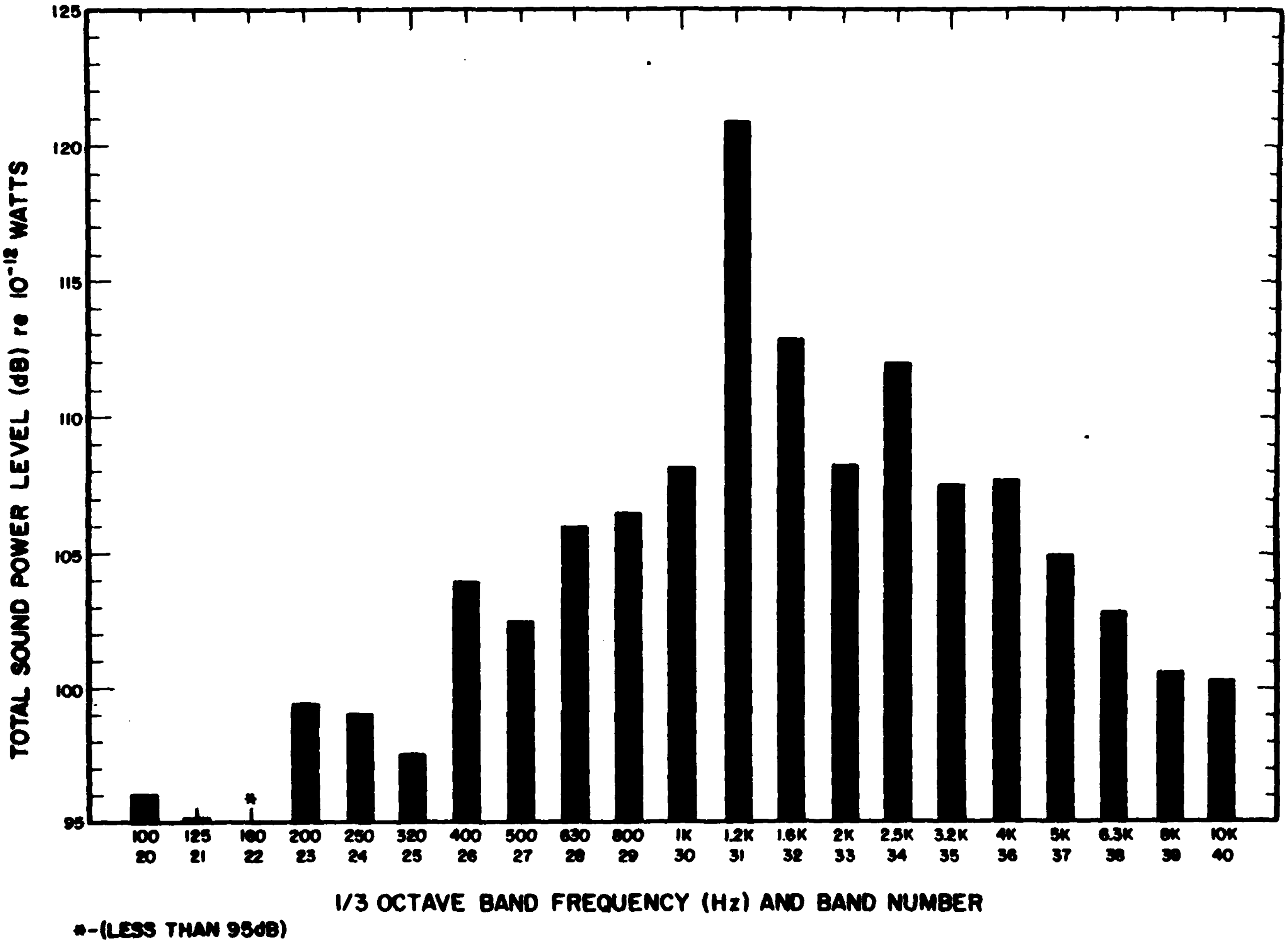


Figure 10. Total sound power level spectrum, Aberdeen test.

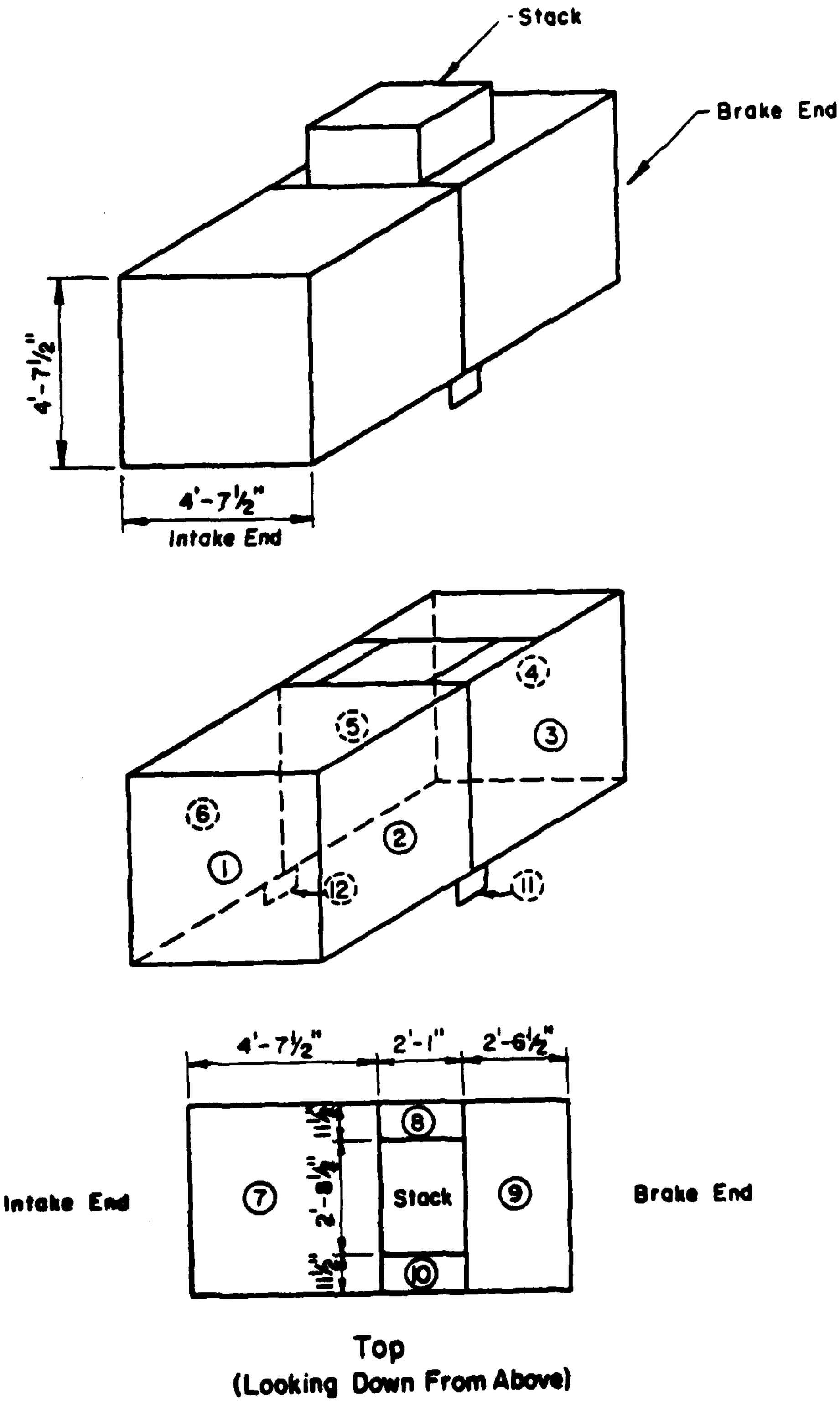
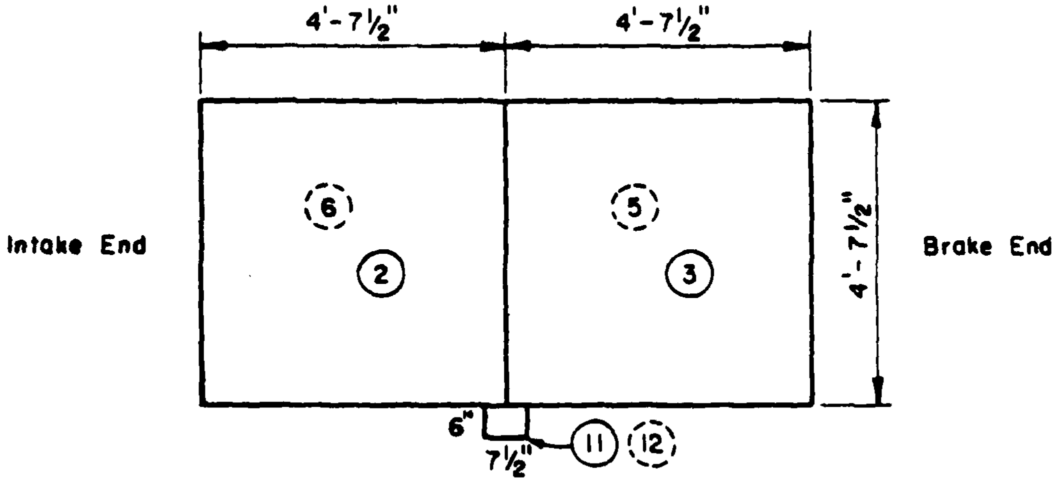
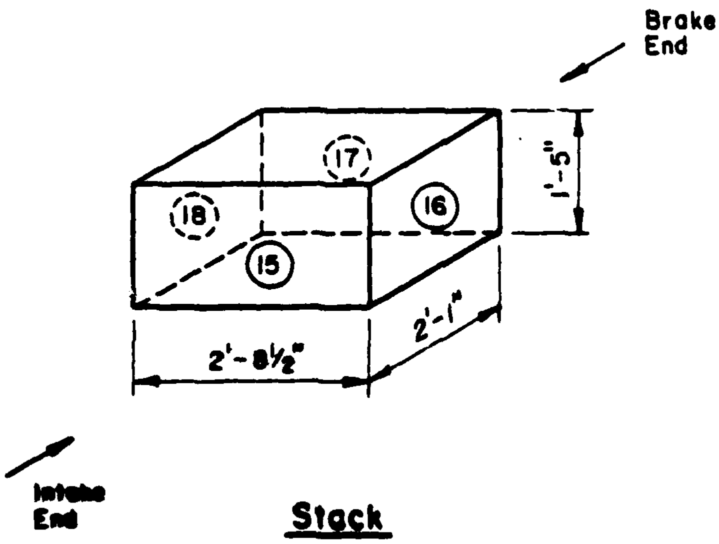


Figure 11. Outdoor test configuration.



Side



Stack

Figure 11. (Cont'd.)

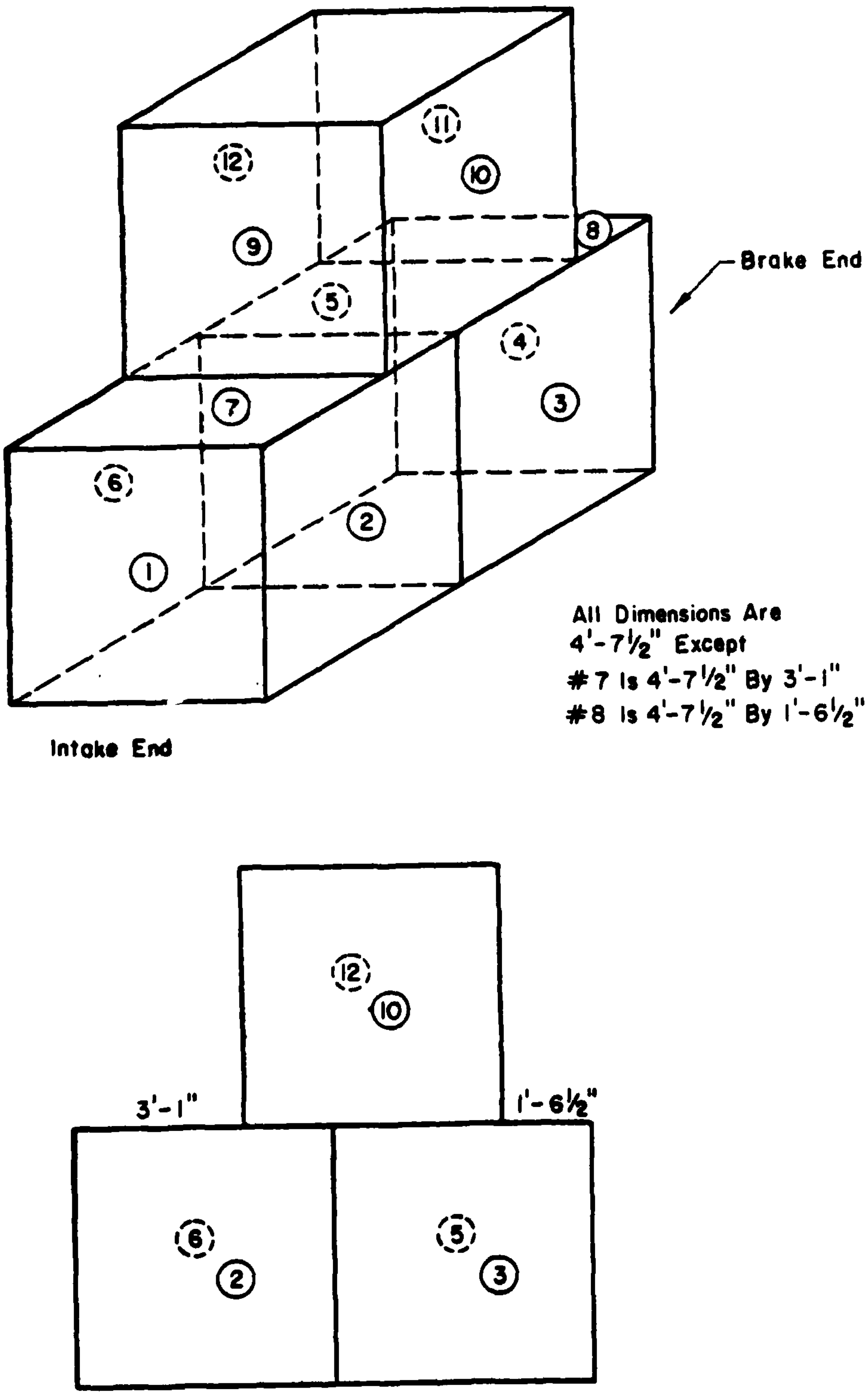


Figure 12. Inside test configuration.

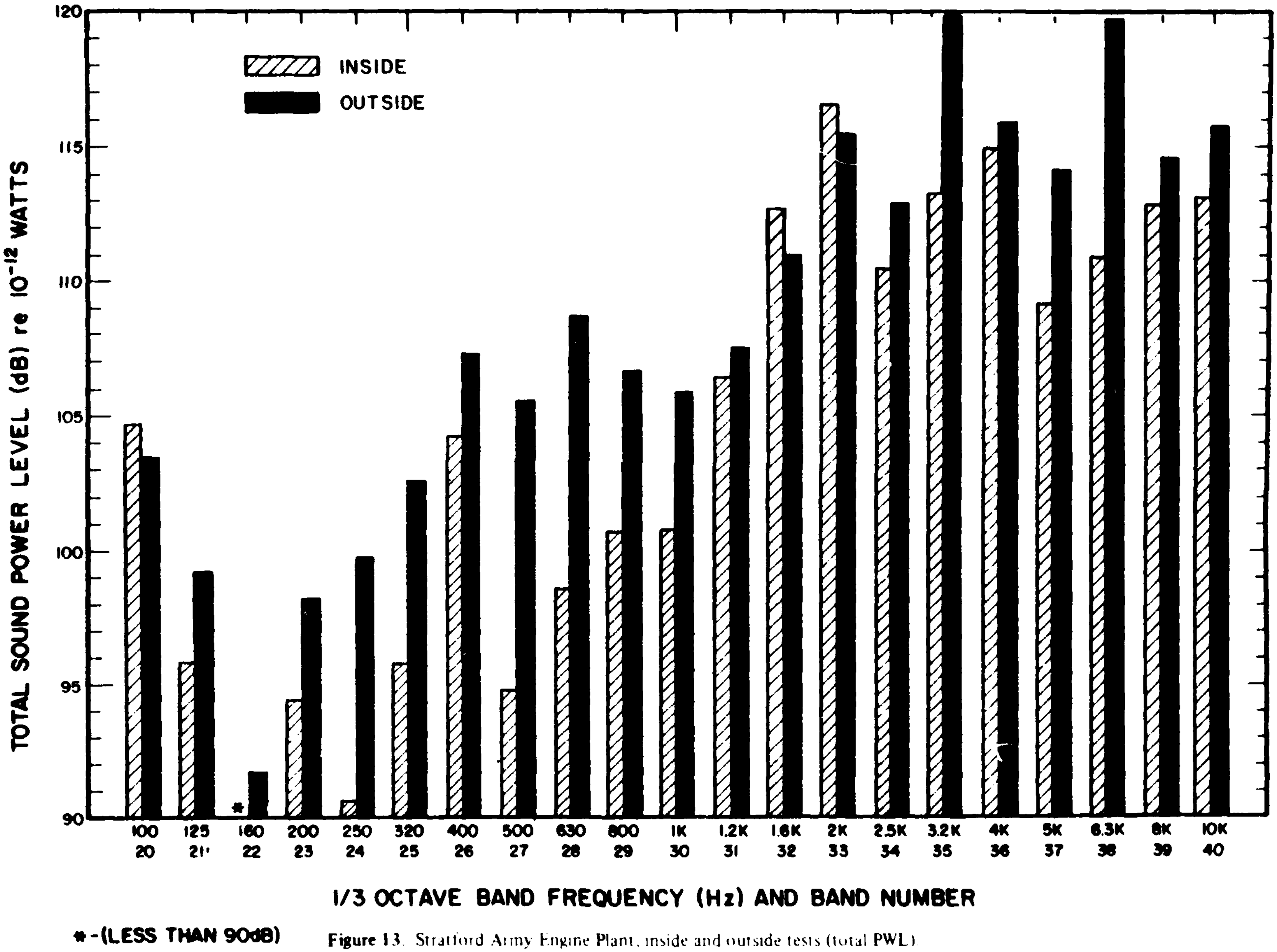


Figure 13. Stratford Army Engine Plant, inside and outside tests (total PWL).

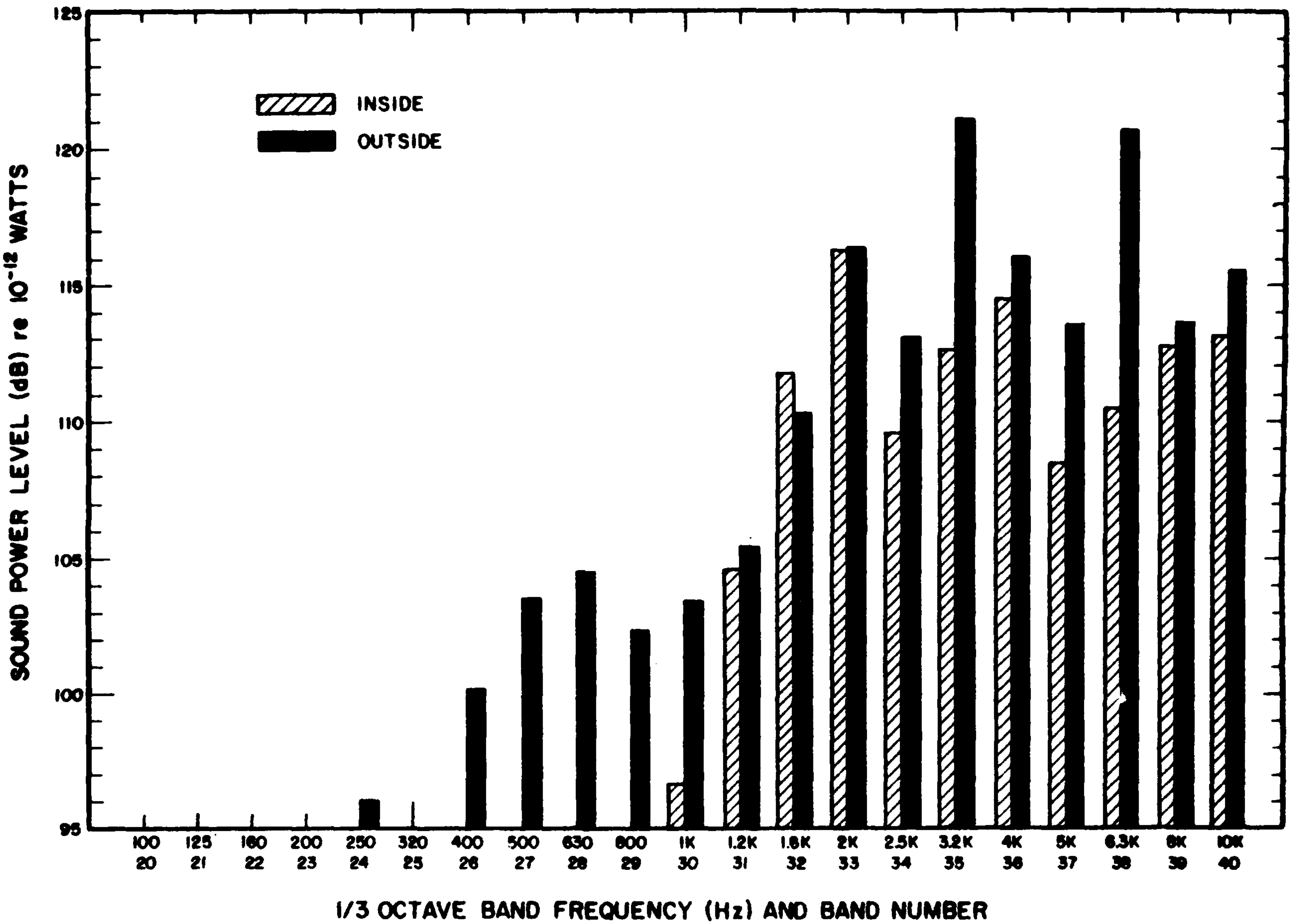


Figure 14. Stratford Army Engine Plant. "Box 1." inside and outside tests (PWL Re: 10^{-12} watts).

4 ACOUSTICAL DESIGN

Interior Acoustic Design

The sound pressure level (SPL) in an inclosed space is given in terms of the sound power level (PWL) emitted by a source (in SI units):

$$SPL = PWL + 10 \log \left(\frac{Q}{4\pi r^2} + \frac{4}{R_T} \right) \quad \text{[Eq 5]}$$

In this Eq 5, Q represents a directivity index of the source. It can be thought of as the ratio of the specific emissions in a given direction as compared with an omnidirectional source of the same power. The distance from the source is r. R_T is commonly known as the room constant and is defined by:

$$R_T = \frac{S\bar{a}}{1 - \bar{a}} \quad \text{[Eq 6]}$$

In Eq 6, S is the surface area in square meters and a is the average absorption coefficient. Basically, the first term in Eq 5 represents the source strength. The second term in Eq 5 describes the constituents of the interior sound field. It incorporates two terms, the direct field and the reverberant field. The direct field term takes into account the source's directivity, Q, and the $\frac{1}{r}$ sound decay with distance. The latter term ($4/R_T$) represents the reverberant field contribution. It builds up in an enclosed space and is a function of the surface area and average absorption in the room. Basically, the larger the surface area and the greater the absorption, the lower the reverberant sound field.

At any point in a room, the total sound field is the sum of the direct field and the reverberant field. Figure 15 illustrates the sound fields in a room as one moves radially from a source. The direct field decays as $\frac{1}{r}$; the reverberant field is a constant. "Near" the source, the direct field predominates. Where the reverberant field (in energy density) is much smaller than the direct field, it can be ignored when calculating the resulting total field, with no significant loss in accuracy. "Far" from the source, the reverberant field predominates and the direct field can be ignored when calculating the resulting total field.

Figure 15 also indicates the total sound field level. Note that the two fields, expressed as levels in decibels, are added logarithmically by:

$$L_{TOTAL} = 10 \log \left(10^{\frac{L_{Direct}}{10}} + 10^{\frac{L_{Reverb.}}{10}} \right) \quad \text{[Eq 7]}$$

"Near" and "far" are controlled by the source size, room size, and room absorption.

A typical engine test cell for new construction or maintenance will have a surface area on the order of 80 m². Since hard concrete might have an absorption coefficient of 0.025, the resulting room constant (R_T)

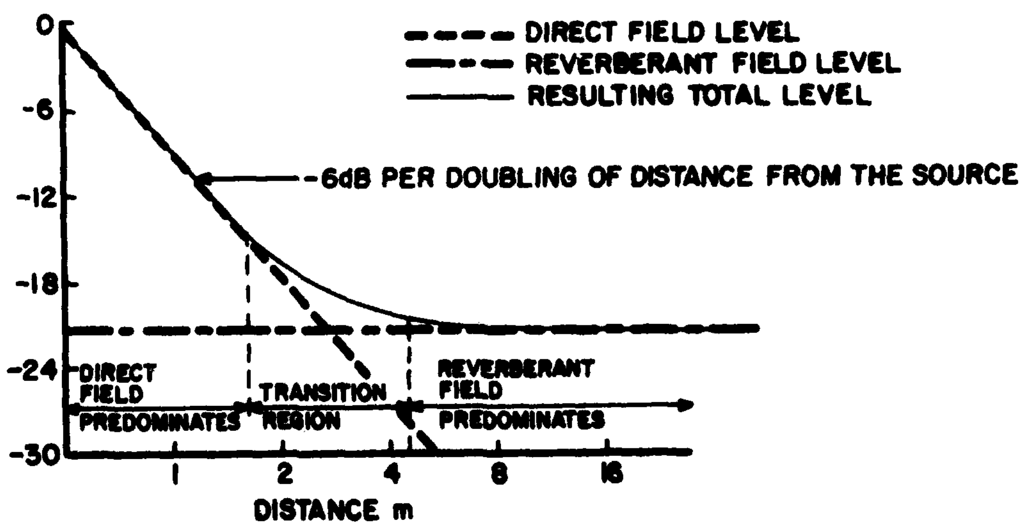


Figure 15. Description of sound field around sound source in reverberant room.

is on the order of 2. Normally, a test cell is not occupied in a production or maintenance facility. If an occupant were internal, he or she might be 1 to 2 m from the source. With these types of dimensions (and an average directivity factor Q of 1), the direct source field contributes a term on the order of $\frac{1}{20}$, and the reverberant field contributes a term on the order of 2. Clearly, in this instance, the reverberant field predominates and is the main factor contributing to the sound pressure in the inclosed space. Since energy leaving the test cell for other parts of the facility is directly proportional to the average sound level in the test cell itself, the reverberant field is also the primary factor contributing to power radiated through the test cell walls and doors to other parts of the facility.

The reverberant field in the test cell is easily reduced by using sound-absorbing material. For example, an average absorption coefficient $\bar{a}$ of 0.2 will change the room constant from 2 to 20. This will yield a 10-dB reduction in the reverberant sound field. An average absorption coefficient of 0.5 results in a room constant of 80, and the reverberant sound field is lessened by 16 dB as compared with the hard concrete case. At this point, the direct and reverberant field will be almost the same, so there is no point in adding more absorption to the room. In fact, an average absorption $\bar{a}$ of about 0.2 is probably about the best bargain, since 10 dB area gained in going from what is essentially hard walls to walls with an average absorption of 0.2. Only another 6 dB are gained by more than doubling the average absorption from 0.2 to 0.5.

Interior Acoustic Design Options

As noted, the primary sound source measured at the Stratford Army Engine Plant was the engine air outlet. The test cell already requires a large air inlet opening to the outdoors to provide the air needed to run and cool the engine. If an acoustically lined and muffled duct were run from the outdoor inlet to the air inlet on the engine, the initial sound power in the test cell could be reduced by about 10 dB. Adding sound-absorbing materials with an absorption coefficient of 0.2 to the walls will lower the cell noise levels by another 10 dB. Thus, the total level in the test cell can be reduced by 20 dB over the present hard-surface, no-duct case.

Indoor levels in a control room next to the test cells should be kept to about 60 dB(A), or less. Without treating the test cells, special heavy doors, walls, and windows are needed to provide 60 to 70 dB of isolation. If wall absorption and an inlet duct can lower the level 20 dB, the walls and doors of the control room would only need to attenuate the sound by 40 to 50 dB instead of the 60 to 70 dB required without an inlet ducting or wall absorption in the test cell. So it becomes a tradeoff between better sound reducing doors and walls or absorption in the room and a duct to the air inlet. In either case, some kind of muffler section may be required between the outside and the test cell, both for the inlet and the exhaust.

The engine test cells at the training facility to be built at Aberdeen Proving Ground will regularly have personnel within the cell. This is because Aberdeen is a teaching facility, rather than a construction or rework facility. At the training facility, the main noise source appears to be related to the transmission. Unlike the engine alone, there are no predominant "hot spots" which radiate noise. The noise levels are high and ducting the inlet does not appear to be an effective method for lowering the overall noise level. As with the test cells, acoustical absorbing materials on the wall will lower the ambient noise level. However, there is no reason to have an average absorption coefficient greater than about 0.2, since the direct field at distances of about 1 m will begin to predominate over the reverberant field if greater absorption is included. Adding absorption material will lower the reverberant field by about 10 dB. With an 80 m^2 cell surface and no absorbing material, the SPL in the cell will be on the order of 128 dB. The absorbing materials will lower this level to 118 dB, which is definitely an improvement both for personnel in the test cell and in terms of sound isolation requirements to adjacent parts of the facility. Nevertheless, hearing protection devices will still clearly be required and communications will rely on electronic hardware.

Exterior/Environmental Acoustic Design

Since exhaust noise could not be measured near the engines because of the high-flow velocities and elevated temperatures, an outdoor free-field measurement must be used to obtain these data, as required.

Department of Defense guidance on environmental noise indicates that daytime average levels should be kept below about 65 dB(A) for a *continuous* source. Nighttime levels need to be reduced by about 10 dB, to 55 dB(A). However, the M1E1 engine produces substantial low-frequency energy. This low-frequency energy may cause walls to vibrate noticeably. This vibration can result in a significant community reaction not totally accounted for in the A-weighted measure.

In most cases, the required noise reduction (if any) needed for environmental purposes should be relatively modest and achievable by lining the exhaust duct and

putting two 90° bends in the exhaust duct. Materials such as those used in jet-engine nacelles will withstand the temperatures and flows present in the cell.

5 CONCLUSIONS

This study developed the required sound power data for interior acoustic design. In the process, sound intensity measurement has been demonstrated as a very powerful technique for determining design options. In particular:

1. An average absorption on test cell surfaces of 0.2 will lower interior levels by 10 dB.

2. For an engine plant, inlet ducting can achieve an additional 10-dB reduction in cell interior noise levels.

APPENDIX A: ABERDEEN DATA (See Figure 7 for locations)

The power (P) is derived from the measured intensity levels (L_{I_i}) using Eq 2. Intensity levels are converted to units proportioned to intensity ($I_i \alpha\ 10^{L_{I_i}/10}$), multiplied by their respective area in square meters S_i, and summed:

$$P = \sum_i 10^{L_{I_i}/10} \times S_i \times 10^{-12} \qquad \text{[Eq A1]}$$

The power is converted to sound power level (PWL) by

$$PWL = 10 \log (P \times 10^{12}),$$

$$= 10 \log (P) + 120. \qquad \text{[Eq A2]}$$

For the data in Appendices A and B, a number of averages, N, were made on each rectangular surface so Eq A1 becomes

$$P = \sum_i \frac{1}{N_i} 10^{L_{I_i}/10} \times S_i \times 10^{-12} \qquad \text{[Eq A3]}$$

where N_i is given at the top of each column in the appendices. For example the power radiated through side A in the 160 Hz, one-third octave band is:

$$\begin{aligned} P = \Big(& \tfrac{1}{4} \times 10^{8.22} \times 1.11 - \tfrac{1}{3} \times 10^{8.09} \times 1.11 \\ & - \tfrac{1}{3} \times 10^{8.19} \times 1.11 + \tfrac{1}{3} \times 10^{7.80} \times 1.11 \\ & + \tfrac{1}{3} \times 10^{8.40} \times 1.11 + \tfrac{1}{4} \times 10^{8.69} \times 1.11 \\ & + \tfrac{1}{3} \times 10^{7.80} \times 1.11 + \tfrac{1}{3} \times 10^{8.64} \times 1.11 \\ & + \tfrac{1}{3} \times 10^{8.54} \times 1.11 \Big) \times 10^{-12} \end{aligned}$$

$$= .509 \text{ mW}$$

where 1.11 is the area in square meters of a 3 ft. by 4 ft. surface. Had the surface areas been different, then each S_i (currently 1.11) would have been different. The power level radiated through side A in the 160 Hz, one-third octave band is given by Eq 2. It is

$$L_{P_{160-A}} = 10 \log (.509 \times 10^{-3}) + 120$$

$$= -32.9 + 120$$

$$= 87.1 \text{ dB}$$

Location: **Test: Aberdeen** **Date: 14 July 82**

Band/Freq	Box Mike/Spacer N	A-1 ½–12 4	A-2 ½–12 3	A-3 ½–12 3	A-4 ½–12 3	A-5 ½–12 3	A-6 ½–50 4	A-7 ½–12 3	A-8 ½–12 3	A-9 ½–12 3
20	100	88.0	0	0	80.0	84.0	87.3	82.4	87.4	82.4
21	125	85.4	0	0	81.4	83.0	84.4	84.7	83.4	83.0
22	160	82.2	−80.9	−81.9	78.0	84.0	86.9	78.0	86.4	85.4
23	200	87.0	0	0	82.4	85.3	86.0	88.3	87.4	85.7
24	250	87.4	76.0	77.0	84.3	86.8	87.7	87.4	88.0	88.3
25	330	89.1	−76.7	−79.7	86.3	86.9	89.6	86.4	88.3	88.1
26	400	91.9	81.4	81.9	90.7	91.0	95.0	90.2	91.8	93.8
27	500	89.9	79.7	79.3	89.4	89.6	91.5	89.6	90.9	90.5
28	630	95.4	83.7	83.4	93.4	93.7	95.6	93.1	95.1	95.7
29	800	94.9	84.6	86.3	92.0	93.1	95.9	93.0	92.5	93.6
30	1 K	96.1	85.6	86.5	94.3	95.0	98.5	94.3	94.1	96.2
31	1.25 K	108.4	97.0	96.9	103.6	106.5	110.1	103.4	106.7	110.6
32	1.6 K	100.1	88.6	90.3	99.0	100.0	101.9	99.0	99.7	101.4
33	2 K	96.0	83.9	85.5	95.6	97.0	97.9	95.2	96.1	97.5
34	2.5 K	98.8	97.4	89.4	98.5	101.7	101.4	98.7	100.7	103.1
35	3.2 K	93.4	85.1	86.1	96.2	97.7	93.7	95.3	96.8	98.3
36	4 K	89.6	84.8	85.6	96.3	98.1	78.9	95.7	97.0	99.2
37	5 K	−87.7	85.2	84.9	95.4	97.1	−91.9	93.1	94.7	97.5
38	6.3 K	−84.1	82.7	83.7	94.6	94.5	−85.0	91.6	91.6	94.4
39	8 K	77.9	80.3	80.6	92.2	92.6	82.7	90.7	89.5	93.1
40	10 K	79.8	80.5	80.9	92.7	91.9	78.4	91.6	90.3	93.1
	Total	104.8	95.2	95.6	104.1	106.1	106.5	103.8	105.8	108.7

Location:					Test: Aberdeen					Date: 14 July 82
	Box	B-1	B-2	B-3	B-4	B-5	B-6	B-7	B-8	B-9
	Mike/Spacer	½–12	½–12	½–12	½–12	½–12	½–12	½–12	½–50	½–12
Band/Freq	N	3	3	3	3	3	3	3	4	3
20	100	80.0	0	0	0	−83.4	0	0	87.0	0
21	125	0	0	0	0	0	0	79.0	84.0	0
22	160	−82.7	81.9	−82.7	−83.4	83.4	−79.7	−81.9	0	−90.9
23	200	81.4	79.4	82.4	83.5	85.1	81.0	78.0	87.3	0
24	250	77.0	77.8	81.1	79.5	81.4	77.0	0	88.6	0
25	330	0	0	0	0	0	−78.9	76.7	89.6	87.9
26	400	84.1	88.1	88.2	87.6	86.3	82.7	84.0	94.6	90.7
27	500	80.4	82.4	84.0	84.9	83.9	80.4	80.6	92.7	84.0
28	630	85.0	88.0	88.2	88.8	87.0	82.9	84.1	98.5	83.8
29	800	86.0	88.2	90.0	89.3	88.9	86.3	86.0	97.2	91.3
30	1 K	87.1	89.1	91.0	90.9	89.2	86.5	87.8	99.2	92.6
31	1.25 K	99.5	102.1	106.6	104.4	102.0	98.3	99.5	115.1	108.0
32	1.6 K	90.8	92.5	95.3	94.3	92.9	89.6	89.7	104.7	96.9
33	2 K	86.2	87.7	89.7	88.5	87.0	83.8	85.3	100.0	90.2
34	2.5 K	88.1	91.4	95.9	92.6	92.4	85.7	88.9	103.9	94.9
35	3.2 K	85.1	87.2	89.6	87.4	86.6	83.1	84.4	98.0	92.2
36	4 K	84.5	87.5	91.1	87.9	86.5	82.9	83.0	97.4	93.4
37	5 K	83.2	85.0	87.3	84.1	83.1	76.6	79.2	93.2	88.0
38	6.3 K	81.8	83.4	83.7	80.0	79.3	74.9	79.9	86.9	88.4
39	8 K	80.4	81.4	80.3	75.3	73.2	70.0	77.1	82.4	82.5
40	10 K	80.5	81.6	79.6	73.2	70.0	70.0	77.9	80.0	81.4
	Total	97.2	99.6	103.6	101.5	99.6	95.8	96.9	110.8	104.8

Location:					Test: Aberdeen					Date: 14 July 82
	Box	B-10	B-11	B-12	B-13	B-14	B-15	B-16	B-17	B-18
	Mike/Spacer	½–12	½–12	½–12	½–12	½–12	½–12	½–50	½–12	½–12
Band/Freq	N	3	3	3	3	3	2	4	3	4
20	100	80.0	0	0	0	0	81.0	88.0	0	0
21	125	0	0	0	79.0	0	0	87.4	0	0
22	160	−82.7	−83.4	−80.9	−82.7	−83.4	−79.7	86.4	−81.9	−82.7
23	200	84.6	84.0	78.0	81.0	81.4	82.4	91.9	83.0	81.8
24	250	80.4	81.1	78.4	78.4	79.0	78.4	93.0	82.5	80.0
25	330	79.0	78.5	0	−77.9	0	−76.7	93.4	76.8	−76.7
26	400	87.1	86.7	81.6	86.1	88.9	84.9	94.8	87.0	85.6
27	500	84.6	84.9	80.0	82.4	83.9	83.0	94.8	84.9	82.3
28	630	90.0	88.7	82.9	87.6	88.9	88.8	97.4	89.4	86.4
29	800	89.5	89.7	86.1	87.1	88.3	87.9	99.3	89.6	87.5
30	1 K	92.1	91.4	86.9	87.7	89.0	89.4	101.3	90.9	88.5
31	1.25 K	106.9	104.3	98.4	101.3	104.4	105.7	113.7	103.3	101.1
32	1.6 K	94.0	94.9	90.3	91.2	94.1	74.4	105.5	94.2	91.5
33	2 K	89.3	88.9	84.0	85.1	87.7	88.0	101.1	88.4	85.6
34	2.5 K	94.8	93.7	85.5	87.9	90.4	92.8	104.1	93.5	88.9
35	3.2 K	88.3	88.4	83.4	84.1	86.1	87.1	98.6	87.5	84.9
36	4 K	89.0	89.8	82.5	83.1	86.1	88.4	97.4	89.1	84.9
37	5 K	85.7	86.0	72.3	74.9	82.6	84.4	89.7	83.9	79.9
38	6.3 K	81.0	82.7	75.4	78.1	79.5	80.3	80.0	80.6	77.0
39	8 K	76.1	77.8	70.0	74.7	74.7	75.3	80.0	74.1	70.5
40	10 K	73.3	73.8	70.0	75.7	74.1	73.2	80.0	70.0	70.1
	Total	103.6	101.7	95.9	98.4	101.3	103.9	110.1	100.9	97.1

Location: Test: Aberdeen Date: 14 July 82

Band/Freq	Box Mike/Spacer N	C-1 ½–12 6	C-2 ½–12 3	C-3 ½–50 4	C-4 ½–12 3	C-5 ½–12 3	C-6 ½–12 3	C-7 ½–12 3	C-8 ½–50 4	C-9 ½–12 3
20	100	85.7	83.0	84.1	0	−81.9	0	0	−86.0	0
21	125	81.4	0	79.5	0	78.0	0	0	0	0
22	160	−79.7	−81.9	82.6	−81.9	0	−80.9	−81.9	−74.9	−82.7
23	200	82.7	77.0	82.0	0	−77.9	77.0	−77.0	72.0	80.5
24	250	80.0	0	81.7	0	78.8	0	0	74.0	0
25	330	−84.4	−77.9	79.3	−77.9	77.8	−76.7	−79.7	0	−78.9
26	400	0	79.1	80.6	81.2	79.8	80.7	80.0	84.3	82.9
27	500	87.4	79.5	84.9	78.4	83.9	80.8	78.1	−73.4	80.4
28	630	84.3	80.7	88.8	81.3	84.3	82.2	80.4	−70.4	89.0
29	800	83.0	84.0	89.4	84.1	94.5	85.4	83.5	−82.7	84.9
30	1 K	−78.4	84.8	84.7	84.4	87.9	86.0	83.8	−79.1	85.5
31	1.25 K	99.4	96.0	−96.1	96.3	81.1	95.7	94.0	−86.4	95.3
32	1.6 K	−81.0	88.3	90.1	88.0	79.0	89.3	87.8	−81.3	88.9
33	2 K	−78.4	81.9	89.0	81.3	79.9	82.3	80.6	−78.0	82.4
34	2.5 K	83.9	81.0	79.9	80.9	78.2	82.2	80.0	−84.7	82.0
35	3.2 K	−82.1	80.7	75.5	80.4	70.0	81.2	80.0	−79.0	81.0
36	4 K	−84.5	79.7	−85.7	78.9	0	79.0	78.4	−80.8	79.1
37	5 K	−76.3	70.0	−82.4	0	0	70.0	70.0	−74.5	70.0
38	6.3 K	−72.9	70.0	−75.3	0	70.0	70.0	70.0	70.0	70.0
39	8 K	−76.1	0	70.0	0	0	0	0	70.0	0
40	10 K	−76.1	70.0	70.0	70.0	0	70.0	70.0	70.0	0
	Total	92.5	93.5	82.1	93.5	92.2	93.6	91.7	−86.3	93.7

Location: Test: Aberdeen Date: 14 July 82

Band/Freq	Box Mike/Spacer N	D-1 ½–12 3	D-2 ½–12 3	D-3 ½–12 3	D-4 ½–12 3	D-5 ½–50 4	D-6 ½–12 3	D-7 ½–12 3	D-8 ½–12 3	D-9 ½–12 3
20	100	82.4	80.0	0	0	84.7	0	0	85.7	85.4
21	125	0	84.7	0	0	80.6	0	0	84.7	87.7
22	160	0	79.8	−89.7	0	80.1	0	0	79.8	82.0
23	200	83.3	88.4	89.4	88.0	85.2	0	81.4	84.9	88.4
24	250	82.0	86.9	88.4	86.0	83.6	0	83.0	87.9	89.4
25	330	85.0	88.9	0	0	85.3	0	85.4	90.0	89.5
26	400	86.5	90.4	91.9	90.0	91.1	0	89.7	91.9	92.6
27	500	86.9	92.1	92.9	92.0	88.5	0	88.9	92.4	92.0
28	630	89.4	95.2	93.9	95.0	93.5	82.0	90.7	95.1	96.1
29	800	91.1	94.2	95.1	94.9	92.7	86.7	92.4	95.5	96.8
30	1 K	93.0	97.1	97.8	96.0	93.4	85.4	96.8	99.3	98.1
31	1.25 K	108.0	112.4	109.4	108.5	105.1	102.4	107.2	111.1	107.1
32	1.6 K	99.1	102.9	102.9	102.0	98.4	91.7	100.9	102.9	103.5
33	2 K	93.8	97.7	98.6	98.0	93.9	89.5	96.1	98.4	99.4
34	2.5 K	97.6	100.5	102.3	101.1	95.6	94.0	99.6	101.4	101.7
35	3.2 K	93.1	96.6	98.4	99.3	91.5	92.7	96.2	97.7	98.3
36	4 K	94.5	98.0	99.4	99.4	87.9	94.3	99.4	100.0	98.2
37	5 K	90.9	94.7	96.7	98.9	−76.2	94.4	94.9	95.6	95.4
38	6.3 K	86.4	91.1	93.5	97.3	−79.0	95.5	90.8	91.9	92.9
39	8 K	82.1	87.5	90.9	95.2	−71.6	94.1	86.8	88.3	90.4
40	10 K	79.5	85.9	89.1	94.7	80.7	93.7	83.9	86.1	88.3
	Total	105.3	109.6	108.0	107.6	102.0	101.6	106.0	109.0	107.2

Location: Test: Aberdeen Date: 14 July 82

Band/Freq	Box Mike/Spacer N	D-10 ½–12 3	D-11 ½–12 3	D-12 ½–12 3	D-13 ½–12 3	D-14 ½–12 3	D-15 ½–50 4	D-16 ½–12 3	D-17 ½–12 3	D-18 ½–12 3
20	100	86.3	0	80.0	81.0	88.1	91.0	89.3	88.4	80.0
21	125	84.7	80.8	0	82.0	89.6	92.1	89.2	87.7	80.0
22	160	81.5	0	0	84.5	89.9	89.9	85.4	82.8	78.0
23	200	87.3	83.0	82.1	85.3	90.3	91.9	87.8	87.5	84.4
24	250	88.4	84.4	83.4	84.1	89.2	92.9	89.7	88.6	84.7
25	330	87.6	85.9	82.4	85.9	89.5	93.1	89.3	88.1	85.0
26	400	90.6	91.5	85.4	94.2	93.6	94.2	92.5	92.1	91.6
27	500	92.2	89.3	86.3	89.6	92.2	93.9	90.8	89.9	86.4
28	630	95.9	93.4	91.8	93.6	95.1	96.6	94.5	94.9	89.8
29	800	96.9	92.3	88.4	93.9	96.5	97.8	94.8	93.2	89.5
30	1 K	97.5	93.7	89.6	97.0	99.2	98.9	96.2	92.6	88.3
31	1.25 K	106.6	104.4	102.6	106.7	107.4	107.2	105.1	104.4	102.7
32	1.6 K	103.0	98.4	95.1	100.9	102.4	103.5	102.0	99.1	94.7
33	2 K	98.8	95.9	92.6	96.8	98.0	98.9	97.9	95.9	91.1
34	2.5 K	100.9	97.1	95.8	102.5	103.2	100.1	99.5	97.4	95.1
35	3.2 K	98.4	95.5	93.5	97.4	97.8	94.5	96.9	94.4	91.5
36	4 K	98.4	95.9	94.3	99.9	98.9	91.4	96.6	94.7	93.4
37	5 K	96.9	95.7	92.6	96.9	95.9	80.4	93.7	92.5	91.0
38	6.3 K	95.5	94.4	91.0	92.1	92.1	−79.2	92.1	90.7	89.0
39	8 K	93.2	92.8	89.4	87.9	88.0	−72.5	90.1	89.4	87.1
40	10 K	91.6	92.2	89.9	85.0	85.8	71.0	88.5	90.2	87.9
	Total	106.9	104.2	102.4	106.5	107.3	105.6	105.5	104.1	101.5

Location: Test: Aberdeen Date: 14 July 82

Band/Freq	Box Mike/Spacer N	E-1 ½–12 3	E-2 ½–12 3	E-3 ½–12 3	E-4 ½–50 3	E-5 ½–12 3	E-6 ½–12 3	E-7 ½–12 3	E-8 ½–12 3
20	100	0	0	0	−83.5	80.0	0	0	0
21	125	0	0	0	83.3	0	0	−80.9	0
22	160	−81.9	−82.7	−82.7	84.1	−81.9	−81.9	78.0	−89.7
23	200	78.8	78.8	84.2	88.8	82.7	78.0	0	0
24	250	0	77.0	79.0	89.8	77.8	0	−78.9	0
25	330	−78.9	−77.9	−76.7	88.9	0	0	82.3	-87.9
26	400	81.4	83.4	85.1	91.3	87.4	83.4	78.7	89.0
27	500	79.0	81.9	82.3	92.2	82.9	81.3	84.1	0
28	630	84.0	86.4	86.7	95.0	88.2	84.7	85.3	83.7
29	800	84.9	86.4	87.4	94.9	88.4	87.0	85.9	85.8
30	1 K	85.0	86.1	87.4	96.7	88.6	86.8	95.9	85.4
31	1.25 K	94.8	96.0	96.6	108.1	98.6	96.7	89.3	94.6
32	1.6 K	88.4	90.4	91.4	101.1	91.0	89.9	83.4	90.4
33	2 K	82.5	85.0	85.1	96.4	85.3	83.1	84.1	83.5
34	2.5 K	81.6	85.3	85.9	99.1	87.5	83.4	84.1	84.7
35	3.2 K	82.9	85.2	84.9	93.8	83.9	81.7	84.3	86.8
36	4 K	83.1	84.5	83.4	92.7	82.6	80.6	82.7	87.1
37	5 K	81.3	84.5	81.4	89.1	77.9	70.0	82.8	88.1
38	6.3 K	82.7	84.8	82.4	78.7	75.5	70.0	80.2	89.3
39	8 K	78.6	83.2	80.1	70.6	70.0	0	81.1	86.6
40	10 K	78.5	83.6	79.8	70.3	70.0	70.6	0	89.0
	Total	94.6	96.4	96.9	107.4	98.1	95.9	95.7	96.0

Location: Test: Aberdeen Date: 14 July 82

Band/Freq	Box Mike/Spacer N	E-10 ½–12 3	E-11 ½–12 3	E-12 ½–12 3	E-13 ½–12 3	E-14 ½–12 3	E-15 ½–50 4	E-16 ½–12 3	E-17 ½–12 3	E-18 ½–12 3
20	100	0	0	0	0	0	85.0	0	80.0	0
21	125	79.0	0	0	0	0	86.0	0	0	0
22	160	–82.7	–83.4	–82.7	–80.9	–80.9	0	–83.4	–84.4	–81.9
23	200	84.9	83.5	0	79.4	81.4	89.9	86.3	81.0	82.7
24	250	81.4	80.0	0	0	76.0	91.0	80.4	80.8	81.4
25	330	0	0	–78.9	–77.9	–77.9	91.0	0	–77.9	76.8
26	400	88.6	87.1	83.5	83.5	85.4	96.0	87.0	85.8	83.6
27	500	85.3	85.0	80.4	80.4	81.6	94.9	85.3	84.6	83.0
28	630	88.4	89.2	84.1	84.1	86.9	98.2	88.5	87.7	85.6
29	800	90.0	89.1	86.3	85.7	87.9	98.9	89.1	88.4	88.4
30	1 K	90.9	90.6	86.6	86.4	88.9	101.3	90.7	89.1	87.7
31	1.25 K	101.8	100.7	96.0	97.1	100.8	117.9	104.7	100.8	100.0
32	1.6 K	93.9	93.1	89.1	89.6	92.4	106.5	94.4	92.1	92.9
33	2 K	89.5	87.7	83.3	84.3	88.0	101.5	88.5	86.7	87.2
34	2.5 K	92.1	90.9	84.5	86.1	91.1	107.7	92.9	89.9	91.1
35	3.2 K	87.7	86.4	82.7	84.2	87.7	99.5	87.3	85.8	88.4
36	4 K	87.4	85.6	81.5	83.9	87.5	96.4	87.9	85.4	89.5
37	5 K	83.7	81.7	72.5	82.5	87.1	90.0	84.3	81.9	85.6
38	6.3 K	80.4	78.9	74.1	83.5	86.9	89.9	80.9	78.7	82.1
39	8 K	74.3	71.8	70.0	80.4	85.7	85.4	75.6	71.8	77.1
40	10 K	70.0	70.0	70.0	80.2	85.8	80.0	72.5	70.0	70.0
	Total	101.1	100.0	95.3	96.6	100.2	114.7	103.0	99.7	99.6

Location: Test: Aberdeen Date: 15 July 82

Band/Freq	Box Mike/Spacer N	AA-1 ½–12 3	AA-2 ½–12 3	AA-3 ½–12 3	BB-1 ½–12 3	BB-2 ½–12 3	BB-3 ½–12 3
20	100	83.0	–80.9	0	83.5	0	83.0
21	125	0	0	0	0	0	0
22	160	–84.4	–82.7	–82.7	–82.7	–81.9	–82.7
23	200	81.4	79.4	78.0	78.8	78.8	87.8
24	250	76.0	78.4	79.5	77.8	79.0	80.4
25	330	–77.9	–78.9	0	–77.9	–76.7	–77.9
26	400	83.3	83.9	87.3	82.9	84.2	86.0
27	500	79.3	80.6	83.0	79.5	81.7	83.0
28	630	81.0	79.8	85.4	80.4	84.3	85.9
29	800	83.3	85.2	87.9	83.4	86.4	88.3
30	1 K	83.1	84.3	86.5	83.5	86.3	88.4
31	1.25 K	94.8	96.6	97.7	95.4	97.7	99.4
32	1.6 K	87.3	88.1	90.2	88.0	89.5	91.4
33	2 K	80.2	81.6	85.0	81.1	84.3	86.3
34	2.5 K	78.1	84.9	88.1	82.4	87.3	90.4
35	3.2 K	80.7	82.6	85.4	81.7	83.6	85.1
36	4 K	79.6	83.0	85.7	81.4	83.1	84.4
37	5 K	74.9	80.6	84.4	75.7	78.5	79.8
38	6.3 K	75.3	80.1	83.3	74.5	76.8	78.2
39	8 K	71.7	78.7	82.1	70.0	72.2	74.7
40	10 K	–76.6	75.5	82.2	70.0	70.0	71.5
	Total	92.6	94.3	96.3	93.3	95.6	97.9

Location: **Test: Aberdeen** **Date: 15 July 82**

Band/Freq	Box Mike/Spacer N	CC-1 ½–12 3	CC-2 ½–12 3	CC-3 ½–12 3	DD-1 ½–12 3	DD-2 ½–12 3	DD-3 ½–12 3
20	100	80.0	0	80.0	0	−80.9	0
21	125	0	0	80.0	80.0	0	0
22	160	−81.9	−83.4	−80.9	−82.7	−82.7	0
23	200	82.1	83.3	86.3	83.0	84.6	88.8
24	250	79.5	82.0	81.1	79.0	80.0	0
25	330	−78.9	0	0	0	0	0
26	400	84.0	85.7	84.7	84.7	85.5	93.9
27	500	78.7	82.7	84.2	80.9	83.9	90.2
28	630	80.1	85.1	86.2	83.3	86.5	91.5
29	800	83.6	86.1	88.4	83.7	87.0	91.5
30	1 K	83.2	87.0	88.4	83.3	86.7	93.7
31	1.25 K	93.5	97.8	100.3	94.5	97.4	108.0
32	1.6 K	87.4	90.2	92.0	87.7	89.4	99.1
33	2 K	80.3	84.8	86.3	80.9	84.3	96.3
34	2.5 K	75.7	86.9	88.4	−76.5	86.2	100.6
35	3.2 K	80.3	83.6	84.4	80.4	83.4	96.6
36	4 K	78.9	83.0	83.7	79.0	82.5	97.9
37	5 K	70.0	76.9	77.1	70.0	77.2	94.7
38	6.3 K	71.5	75.3	75.4	71.3	75.5	91.9
39	8 K	70.0	70.0	70.5	70.0	70.0	90.3
40	10 K	70.0	70.0	70.0	71.3	70.0	89.1
	Total	91.9	95.8	98.0	92.7	95.5	106.3

APPENDIX B:
STRATFORD ARMY ENGINE PLANT DATA
(See Figures 11 and 12 for locations)

Location: **Test: Inside** **Date: 19 Aug 82**

Band/Freq	Box Mike/Spacer N	1 ¼–12 2	2 ¼–12 2	3 ¼–12 4	4 ¼–12 2	5 ¼–12 2	6 ¼–12 2	7 ¼–12 2	8 ¼–12 4	9 ¼–12 4
20	100	−100.9	93.5	−100.6	101.4	−99.7	93.2	−96.4	−89.0	101.2
21	125	0	−95.9	−99.5	94.4	−95.9	−85.6	93.4	100.3	99.1
22	160	0	−88.2	−87.7	0	−86.5	−78.9	−90.4	−94.4	0
23	200	0	−81.7	81.0	0	0	0	0	−86.3	88.8
24	250	0	0	82.5	80.0	0	79.5	0	−82.5	0
25	330	0	86.3	90.5	82.8	89.4	85.1	0	87.9	89.4
26	400	0	94.4	98.1	92.4	95.5	92.5	90.7	95.0	98.7
27	500	0	84.6	88.0	82.6	84.8	84.1	88.1	77.7	83.0
28	630	0	91.2	92.4	87.4	90.6	85.4	82.0	86.9	90.1
29	800	92.0	89.6	94.3	90.8	93.3	89.5	83.4	94.1	90.3
30	1 K	96.7	88.6	92.9	87.7	89.9	88.4	89.3	82.6	89.7
31	1.25 K	104.5	96.1	95.7	89.4	88.9	94.9	98.0	94.0	−91.4
32	1.6 K	111.8	100.9	96.9	−78.2	−80.5	99.1	102.5	97.7	−97.4
33	2 K	116.2	99.6	94.0	91.5	−89.0	98.8	100.4	92.9	−97.9
34	2.5 K	109.4	97.4	92.0	92.3	−87.0	98.0	101.9	94.0	−95.2
35	3.2 K	112.6	98.7	93.2	91.9	−91.3	98.0	102.1	95.9	−97.0
36	4 K	114.4	100.6	−87.5	90.9	−93.5	99.5	103.9	96.4	−95.4
37	5 K	108.4	94.1	89.4	91.0	83.9	95.0	98.5	94.7	−89.4
38	6.3 K	110.4	93.9	92.9	90.8	89.7	94.3	98.3	96.0	−91.9
39	8 K	112.8	94.0	82.5	85.0	−86.3	93.8	97.8	90.9	−97.6
40	10 K	113.0	95.0	−81.0	78.7	−88.1	94.7	99.3	92.0	−98.0
	Total	122.3	108.1	97.5	104.8	−99.4	107.6	109.0	98.7	−94.5

Location: **Test: Inside** **Date: 19 Aug 82**

Band/Freq	Box Mike/Spacer N	10 ¼–12 2	11 ¼–12 4	12 ¼–12 2	13 ¼–12 4	14 ¼–12 4
20	100	100.3	96.7	101.7	101.7	90.0
21	125	−93.4	98.0	−87.7	97.9	97.6
22	160	87.9	89.0	83.7	0	89.8
23	200	85.1	91.8	87.3	87.0	91.4
24	250	83.8	86.0	83.0	87.8	0
25	330	86.3	0	86.1	0	0
26	400	93.0	90.5	95.3	93.1	91.8
27	500	83.9	84.0	85.1	86.0	86.5
28	630	86.8	87.1	87.9	88.7	90.6
29	800	88.7	90.4	89.5	90.0	89.4
30	1 K	88.5	90.0	88.4	89.6	89.9
31	1.25 K	85.5	90.9	88.3	−89.2	90.4
32	1.6 K	−75.7	93.9	88.9	−96.0	93.4
33	2 K	90.9	88.5	92.3	−96.0	92.5
34	2.5 K	88.3	92.1	84.5	−93.4	91.5
35	3.2 K	92.0	84.7	83.4	−96.5	89.0
36	4 K	90.4	80.0	−87.3	−98.7	84.9
37	5 K	86.1	85.4	82.6	−91.9	0
38	6.3 K	86.7	87.3	85.5	−94.2	86.4
39	8 K	82.9	86.2	88.3	−97.1	0
40	10 K	84.6	85.7	88.7	−97.3	85.3
	Total	103.1	101.1	104.2	−97.1	100.5

Location:						Test: Outside				Date: 18 Aug 82
	Box	1	2	3	4	5	6	7	8	9
	Mike/Spacer	¼-12	¼-12	¼-12	¼-12	¼-12	¼-12	¼-12	¼-12	¼-12
Band/Freq	N	3	3	3	2	2	2	4	2	4
20	100	0	93.3	93.9	92.1	95.6	93.4	-102.9	-103.0	-103.9
21	125	0	89.5	90.7	90.9	91.3	90.4	-99.9	100.5	101.2
22	160	0	87.3	86.7	85.0	85.4	87.9	101.9	95.1	96.4
23	200	0	89.5	84.9	86.4	84.9	89.7	98.7	90.9	93.9
24	250	96.0	90.2	86.1	84.4	84.6	90.4	99.4	91.0	89.8
25	330	0	92.2	89.7	85.8	94.2	92.3	100.0	98.1	79.8
26	400	100.0	96.0	98.9	94.3	101.5	98.5	98.3	103.7	93.2
27	500	103.5	97.1	90.0	86.9	88.1	96.1	99.9	0	86.1
28	630	104.5	100.6	99.3	92.0	95.3	98.9	99.6	102.1	97.4
29	800	102.3	98.4	97.2	91.3	95.3	96.9	0	98.4	95.5
30	1 K	103.3	97.5	96.5	89.2	94.1	95.4	-98.4	94.6	88.1
31	1.25 K	105.4	98.9	96.5	89.2	95.8	96.6	0	90.1	90.0
32	1.6 K	110.2	102.3	96.0	89.7	94.9	99.8	103.4	92.9	91.2
33	2 K	116.3	104.1	95.0	90.7	93.7	98.7	104.9	93.7	91.9
34	2.5 K	113.0	101.2	95.2	93.5	92.1	97.9	106.7	98.8	89.7
35	3.2 K	121.0	107.0	98.1	94.4	93.9	101.9	110.9	99.6	91.8
36	4 K	116.0	102.9	94.5	92.3	93.4	102.8	111.3	98.5	90.6
37	5 K	113.5	102.5	95.4	92.0	93.4	100.2	111.1	99.8	88.6
38	6.3 K	120.5	107.6	98.0	94.8	96.5	102.7	112.9	101.0	98.4
39	8 K	113.7	101.2	93.0	89.1	90.0	98.7	112.4	98.1	73.6
40	10 K	115.6	100.6	91.2	87.1	89.4	97.1	112.7	98.1	83.4
	Total	124.7	112.6	106.7	101.2	107.5	111.4	116.8	98.9	-97.1

Location:				Test: Outside			Date: 18 Aug 82	
	Box	10	11	12	15	16	17	18
	Mike/Spacer	¼-12	¼-12	¼-12	¼-12	¼-12	¼-12	¼-12
Band/Freq	N	2	2	2	2	2	2	2
20	100	-101.0	97.9	99.6	105.7	106.0	105.4	105.3
21	125	98.6	90.9	93.6	102.5	101.6	101.4	101.7
22	160	-95.1	0	0	99.8	96.4	103.4	94.5
23	200	-91.3	77.9	83.0	103.7	96.4	97.9	94.4
24	250	-88.4	87.1	87.9	105.1	93.0	92.7	92.0
25	330	92.4	97.5	102.9	105.7	101.6	100.3	93.7
26	400	97.7	105.0	96.4	107.4	96.9	95.3	94.4
27	500	85.4	91.5	81.0	108.0	93.8	93.0	93.9
28	630	97.9	86.8	93.7	108.4	97.4	98.4	96.9
29	800	95.9	91.4	90.0	107.7	94.9	95.0	94.9
30	1 K	90.7	91.5	95.2	107.1	95.7	94.5	94.2
31	1.25 K	89.8	90.3	85.1	106.9	95.9	92.8	94.7
32	1.6 K	91.9	94.9	82.7	107.0	96.3	93.1	95.9
33	2 K	93.7	87.5	90.3	107.3	97.7	93.1	96.5
34	2.5 K	89.0	83.4	87.1	107.9	99.1	93.4	97.0
35	3.2 K	95.1	-85.3	91.9	108.6	99.9	93.9	98.5
36	4 K	94.8	89.7	82.1	108.3	99.9	93.7	98.5
37	5 K	94.4	-79.7	87.6	108.1	100.4	93.6	98.7
38	6.3 K	97.2	88.7	90.1	109.0	101.8	94.8	100.4
39	8 K	96.8	-74.3	79.8	108.7	97.0	92.5	96.7
40	10 K	95.5	-79.9	-78.9	109.5	95.3	92.0	94.9
	Total	93.2	89.1	88.4	114.4	105.4	105.0	104.1

CERL DISTRIBUTION

Chief of Engineers
ATTN: Tech Monitor
ATTN: DAEN-ASI-L (2)
ATTN: DAEN-CCP
ATTN: DAEN-CW
ATTN: DAEN-CWE
ATTN: DAEN-CWM-R
ATTN: DAEN-CWO
ATTN: DAEN-CWP
ATTN: DAEN-EC
ATTN: DAEN-ECC
ATTN: DAEN-ECE
ATTN: DAEN-ZCF
ATTN: DAEN-ECB
ATTN: DAEN-RD
ATTN: DAEN-RDC
ATTN: DAEN-RDM
ATTN: DAEN-RM
ATTN: DAEN-ZCZ
ATTN: DAEN-ZCE
ATTN: DAEN-ZCI
ATTN: DAEN-ZCM

FESA, ATTN: Library 22060

FESA, ATTN: DET III 79906

US Army Engineer Districts
ATTN: Library
Alaska 99501
Al Batin 09616
Albuquerque 87103
Baltimore 21203
Buffalo 14207
Charleston 29402
Chicago 60604
Detroit 48231
Far East 96301
Fort Worth 76102
Galveston 77550
Huntington 25721
Jacksonville 32232
Japan 96343
Kansas City 64106
Little Rock 72203
Los Angeles 90053
Louisville 40201
Memphis 38103
Mobile 36628
Nashville 37202
New England 02154
New Orleans 70160
New York 10007
Norfolk 23510
Omaha 68102
Philadelphia 19106
Pittsburgh 15222
Portland 97208
Riyadh 09038
Rock Island 61201
Sacramento 95814
San Francisco 94105
Savannah 31402
Seattle 98124
St. Louis 63101
St. Paul 55101
Tulsa 74102
Vicksburg 39180
Walla Walla 99362
Wilmington 28401

US Army Engineer Divisions
ATTN: Library
Europe 09757
Huntsville 35807
Lower Mississippi Valley 39180
Middle East 09038
Middle East (Rear) 22601
Missouri River 68101
North Atlantic 10007
North Central 60605
North Pacific 97208
Ohio River 45201
Pacific Ocean 96858
South Atlantic 30303
South Pacific 94111
Southwestern 75202

US Army Europe
HQ, 7th Army Training Command 09114
ATTN: AETTG-DEH (5)
HQ, 7th Army ODCS/Engr. 09403
ATTN: AEAEN-EH (4)
V. Corps 09079
ATTN: AETVDEH (5)
VII. Corps 09154
ATTN: AETSDEH (5)
21st Support Command 09325
ATTN: AEREH (5)
Berlin 09742
ATTN: AEBA-EN (2)
Southern European Task Force 09168
ATTN: AESE-ENG (3)
Installation Support Activity 09403
ATTN: AEUES-RP

8th USA, Korea
ATTN: EAFE (8) 96301
ATTN: EAFE-Y 96358
ATTN: EAFE-ID 96224
ATTN: EAFE-4M 96208

8th USA, Korea
ATTN: EAFE-H 96271
ATTN: EAFE-P 96259
ATTN: EAFE-T 96212

ROK/US Combined Forces Command 96301
ATTN: EUSA-HHC-CFC/Engr

USA Japan (USARJ)
Ch, FE Div, AJEN-FE 96343
Fac Engr (Honshu) 96343
Fac Engr (Okinawa) 96331

Rocky Mt. Area 80903

Area Engineer, AEDC-Area Office
Arnold Air Force Station, TN 37389

Western Area Office, CE
Vanderberg AFB, CA 93437

416th Engineer Command 60623
ATTN: Facilities Engineer

US Military Academy 10996
ATTN: Facilities Engineer
ATTN: Dept of Geography & Computer Science
ATTN: DSCPER/MAEN-A

Engr. Studies Center 20315
ATTN: Library

AMMRC, ATTN: DRXMR-WE 02172

USA ARRCOM 61299
ATTN: DRCIS-RI-I
ATTN: DRSAR-IS

DARCOM - Dir., Inst., & Svcs.
ATTN: Facilities Engineer
ARRADCOM 07801
Aberdeen Proving Ground 21005
Army Matls. and Mechanics Res. Ctr.
Corpus Christi Army Depot 78419
Harry Diamond Laboratories 20783
Dugway Proving Ground 84022
Jefferson Proving Ground 47250
Fort Monmouth 07703
Letterkenny Army Depot 17201
Natick R&D Ctr. 01760
New Cumberland Army Depot 17070
Pueblo Army Depot 81001
Red River Army Depot 75501
Redstone Arsenal 35809
Rock Island Arsenal 61299
Savanna Army Depot 61074
Sharpe Army Depot 95331
Seneca Army Depot 14541
Tobyhanna Army Depot 18466
Tooele Army Depot 84074
Watervliet Arsenal 12189
Yuma Proving Ground 85364
White Sands Missile Range 88002

DLA ATTN: DLA-WI 22314

FORSCOM
FORSCOM Engineer, ATTN: AFEN-FE
ATTN: Facilities Engineer
Fort Buchanan 00934
Fort Bragg 28307
Fort Campbell 42223
Fort Carson 80913
Fort Devens 01433
Fort Drum 13601
Fort Hood 76544
Fort Indiantown Gap 17003
Fort Irwin 92311
Fort Sam Houston 78234
Fort Lewis 98433
Fort McCoy 54656
Fort McPherson 30330
Fort George G. Meade 20755
Fort Ord 93941
Fort Polk 71459
Fort Richardson 99505
Fort Riley 66442
Presidio of San Francisco 94129
Fort Sheridan 60037
Fort Stewart 31313
Fort Wainwright 99703
Vancouver Bks. 98660

HSC
ATTN: HSLO-F 78234
ATTN: Facilities Engineer
Fitzsimons AMC 80240
Walter Reed AMC 20012

INSCOM - Ch, Instl. Div.
ATTN: Facilities Engineer
Arlington Hall Station (2) 22212
Vint Hill Farms Station 22186

MDW
ATTN: Facilities Engineer
Cameron Station 22314
Fort Lesley J. McNair 20319
Fort Myer 22211

MTMC
ATTN: MTMC-SA 20315
ATTN: Facilities Engineer
Oakland Army Base 94626
Bayonne MOT 07002
Sunny Point MOT 28461

NARADCOM, ATTN: DRDNA-F 071160

TARCOM, Fac. Div. 48090

TRADOC
HQ, TRADOC, ATTN: ATEN-FE
ATTN: Facilities Engineer
Fort Belvoir 22060
Fort Benning 31905
Fort Bliss 79916
Carlisle Barracks 17013
Fort Chaffee 72902
Fort Dix 08640
Fort Eustis 23604
Fort Gordon 30905
Fort Hamilton 11252
Fort Benjamin Harrison 46216
Fort Jackson 29207
Fort Knox 40121
Fort Leavenworth 66027
Fort Lee 23801
Fort McClellan 36205
Fort Monroe 23651
Fort Rucker 36362
Fort Sill 73503
Fort Leonard Wood 65473

TSARCOM, ATTN: STSAS-F 63120

USACC
ATTN: Facilities Engineer
Fort Huachuca 85613
Fort Ritchie 21719

WESTCOM
ATTN: Facilities Engineer
Fort Shafter 96858
ATTN: APEN-IM

SHAPE 09055
ATTN: Survivability Section, CCB-OPS
Infrastructure Branch, LANDA

HQ USEUCOM 09128
ATTN: ECJ 4/7-LOE

Fort Belvoir, VA 22060
ATTN: ATZA-DTE-EM
ATTN: ATZA-DTE-SW
ATTN: ATZA-FE
ATTN: Engr. Library
ATTN: Canadian Liaison Office (2)
ATTN: IWR Library

Cold Regions Research Engineering Lab 03755
ATTN: Library

ETL, ATTN: Library 22060

Waterways Experiment Station 39180
ATTN: Library

HQ, XVIII Airborne Corps and 28307
Ft. Bragg
ATTN: AFZA-FE-EE

Chanute AFB, IL 61868
3345 CES/DE, Stop 27

Norton AFB 92409
ATTN: AFRCE-MX/DEE

Tyndall AFB, FL 32403
AFESC/Engineering & Service Lab

NAFEC
ATTN: RDT&E Liaison Office
Atlantic Division 23511
Chesapeake Division 20374
Southern Division 29411
Pacific Division 96860
Northern Division 19112
Western Division 64066
ATTN: Sr. Tech. FAC-03T 22332
ATTN: Asst. CDR R&D, FAC-03 22332

NCEL 93041
ATTN: Library (Code L08A)

Defense Technical Info. Center 22314
ATTN: DDA (12)

Engineering Societies Library 10017
New York, NY

National Guard Bureau 20310
Installation Division

US Government Printing Office 22304
Receiving Section/Depository Copies (2)

268
1-83

CNA Team Distribution

Chief of Engineers
ATTN: DAEN-ECC-E
ATTN: DAEN-ECE-B
ATTN: DAEN-ECE-I (2)
ATTN: DAEN-ZCF-B
ATTN: DAEN-ECZ-A
ATTN: DAEN-ZCE-D (2)

US Army Engineer District
New York 10007
ATTN: Chief, Design Br
Philadelphia 19106
ATTN: Chief, NAPEN-E
Baltimore 21203
ATTN: Chief, Engr Div
Norfolk 23510
ATTN: Chief, NAOEN-D
Huntington 25721
ATTN: Chief, ORHED
Wilmington 28401
ATTN: Chief, SAWEN-D
Savannah 31402
ATTN: Chief, SASAS-L
Mobile 36628
ATTN: Chief, SAMEN-D
Louisville 40201
ATTN: Chief, Engr Div
St. Paul 55101
ATTN: Chief, ED-D
Chicago 60604
ATTN: Chief, NCCPE-PES
Rock Island 61201
ATTN: Chief, Engr Div
St. Louis 63101
ATTN: Chief, ED-D
Omaha 68102
ATTN: Chief, Engr Div
New Orleans 70160
ATTN: Chief, LMNED-DG
Little Rock 72203
ATTN: Chief, Engr Div
Tulsa 74102
ATTN: Chief, Engr Div
Ft. Worth 76102 (3)
ATTN: Chief, SWFED-D
San Francisco 94105
ATTN: Chief, Engr Div
Sacramento 95814
ATTN: Chief, SPKED-D
Far East 96301
ATTN: Chief, Engr Div
Seattle 98124
ATTN: Chief, EN-DB-ST
Walla Walla 99362
ATTN: Chief, Engr Div
Alaska 99501
ATTN: Chief, NPASA-R

US Army Engineer Division
New England 02154
ATTN: Chief, NEDED-T
North Atlantic 10007
ATTN: Chief, NADEN-T
Middle East (Rear) 22601
ATTN: Chief, MEDED-T
South Atlantic 30303
ATTN: Chief, SADEN-TS
Huntsville 35807
ATTN: Chief, HNDED-CS
ATTN: Chief, HNDED-SR
Ohio River 45201
ATTN: Chief, Engr Div
Missouri River 68101
ATTN: Chief, MRDED-T
Southwestern 75202
ATTN: Chief, SWDED-T
South Pacific 94111
ATTN: Chief, SPDED-TG
Pacific Ocean 96858
ATTN: Chief, Engr Div
North Pacific 97208

6th US Army 94129
ATTN: AFKC-EN

7th Army Combined Arms Trng. Cntr. 09407
ATTN: AETTM-HRD-EHD

Armament & Dev. Command 21005
ATTN: DRDAR-BLT

USA ARRADCOM 07801
ATTN: DRDAR-LCA-OK

DARCOM 22333
ATTN: DRCPA-E
ATTN: DRCIS-A

TRADOC
Ft. Monroe, VA 23651

Ft. Clayton, Canal Zone 34004
ATTN: DFAE

Ft. Detrick, MD 21701

Ft. Leavenworth, KS 66027
ATTN: ATZLCA-SA

Ft. McPherson, GA 30330 (2)

Ft. Monroe, VA 23651 (6)

Ft. Rucker, AL 36360 (2)

Aberdeen Proving Ground, MD 21005
ATTN: DRDAR-BLL
ATTN: STEAP-MT-E

Human Engineering Lab. 21005 (2)

USA-WES 39181

Army Environmental Hygiene Agency 21005

Naval Air Station 92135
ATTN: Code 661

NAVFAC 22332 (2)

Naval Air Systems Command 20360

US Naval Oceanographic Office 39522

Naval Surface Weapons Center 22485
ATTN: N-43

Naval Undersea Center, Code 401 92152 (2)

Bolling AFB, DC 20332
AF/LEEEU

Patrick AFB, FL 32925
ATTN: XRQ

Tyndall AFB, FL 32403
AFESC/TST

Wright-Patterson AFB, OH 45433 (3)

Building Research Advisory Board 20418

Transportation Research Board 20418

Dept of Housing and Urban Development 20410

Dept of Transportation Library 20590

Illinois EPA 62706 (2)

Federal Aviation Administration 20591

Federal Highway Administration 22201
Region 15

NASA 23365 (2)

National Bureau of Standards 20234

Office of Noise Abatement 20590
ATTN: Office of Secretary

USA Logistics Management Center 23801

Airports and Construction Services Dir
Ottawa, Ontario, Canada K1A 0N8

Division of Building Research
Ottawa, Ontario, Canada K1A 0R6

National Defense HQDA
Ottawa, Ontario, Canada K1A 0K2

101
+47
2-83

Schomer, Paul D.
Sound power measurements on the M1E1 engine and total power pack. -- Champaign, Ill : Construction Engineering Research Laboratory ; available from NTIS, 1983.
33 p. (Technical report / Construction Engineering Research Laboratory ; N-150)

1. Tanks (military science) -- noise. I. Title. II. Series: Technical report (Construction Engineering Research Laboratory) ; N-150.